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ZONING IN THE BOLIVIAN TIN BELT.

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ABSTRACT.

This paper deals with vertical and lateral ore zoning in the Bolivian tin belt. Three groups of deposits are distinguished: Group A contains deposits without visible connection with intrusive rocks; this includes the antimony deposits and minor deposits containing Sb, Zn, Pb, Ag, Fe, Cu, Ni, Co, Se, W, Au, and Hg, most of which are epithermal and show little zonal distribution of minerals. Group B includes deposits closely associated with granitic intrusions, and embraces most of the tungsten deposits and many of the prominent tin deposits, as well as many deposits containing Sn, W, Mo, Bi, As, Cu, Fe, Zn, Pb, Ag, Au, Sb, Li, Ti, Ni, Co, Te and Hg; zonal distribution of minerals is particularly well shown in this group. Group C includes those deposits associated with dacitic and rhyolitic intrusive, and to a lesser extent, effusive rocks. Some of the great tin and silver deposits are in this group, and the same elements as those of group B are contained, with the exception of Ti, Li, Nb, Te, Mo and Hg; zonal distribution of minerals is not so well shown in this group, in part because of "telescoping" during deposition.

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INTRODUCTION.

ALTHOUGH zonal distribution of ore minerals within the Bolivian tin belt has been treated to some extent by the writer [1] and is mentioned in many descriptions of individual mines or districts, the present paper is an attempt to summarize all data on this subject, particularly those accumulated in recent studies by the writer.

The Bolivian tin belt (Fig. 1) is an elongate region of arcuate form with the richest deposits in the zone of sharpest curvature. These deposits include Oruro, Huanuni, Llallagua, Colavi and Potosi. The size and abundance of the deposits diminish both to the north and to the south.

Whether there is an apparent connection or not, the deposits of the tin belt are believed to be related to intrusive igneous bodies, chiefly of granitic type, although differentiates through tonalite to diorite are recognized. The diorite is slightly younger than the granite. Ultrabasic rocks are absent. However, basic rocks occur in the western part of the tin belt, and in the Altiplano depression to the West andesitic rocks are closely associated with deposits of copper, silver, lead and zinc. Along the boundary between the tin belt and the copper belt to the west, there is a transition not only in the intrusive igneous rocks from silicic to basic, but in the ores as well. For example, at La Joya (Fig. 1), enargite-tennantite veins occur with quartz-wolframite-gold veins in a dacite intrusive. In this connection it should be noted that the copper mineral belt is limited chiefly to the gently folded and faulted rocks of the Altiplano, whereas the tin belt is a zone of highly compressed and faulted rocks. The lead-silver-zinc deposits occur in both zones.

It is believed by the writer that the ore deposits of the tin belt are related to an underlying large granitic batholith, small parts of which are exposed, particularly in the northern part of the belt. Recent studies show that the deposits of the tin belt are related to the second or principal orogenic epoch in the formation of the Andean mountain system, of probable Miocene age, rather than to the Pliocene.

[1] Ahlfeld, F.: The Bolivian tin belt. ECON. GEOL., 31: 48–72, 1936.

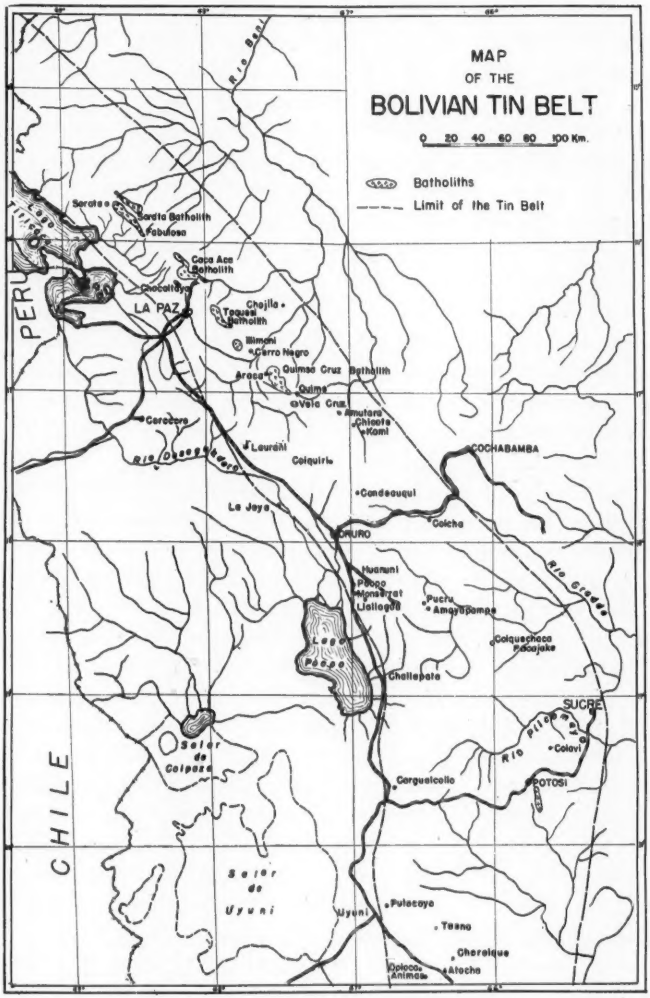


FIG. 1. Map of the Bolivian tin belt.

ORE DEPOSITS OF GROUP A.

Throughout the tin belt, there are innumerable small veins in sedimentary rocks without associated intrusive igneous rocks. The veins occur in Paleozoic, Mesozoic and Tertiary rocks in or closely associated with faults. They are mostly classed as epithermal, and as a group contain the following elements: Sb, Zn, Pb, Ag, Fe, Cu, Ni, Co, Se (limited to the Pacajake blockite vein), W, Au and Hg. Strikingly absent from this list are Sn, Bi and Mo. Although the antimony veins are limited to the tin belt, the copper, lead and zinc veins extend over a much larger area to the east of the tin belt. The ore shoots in this group are nearly all small and occur in otherwise barren quartz or siderite veins. There is no zonal distribution of minerals beyond a general impoverishment with depth, generally from 100 to 300 m. below the surface.

Antimony Veins.—Most of the antimony deposits of Bolivia belong to this group. They have been formed at depths ranging from near the surface to perhaps more than 2000 m. Differences in depth of formation have caused noticeable differences in mineral content. Some veins are closely related to thermal sulphur springs that deposit chalcedonic quartz with stibnite crystals. A vein at the Tarumita mine near Caracollo north of Oruro contains small pockets of cinnabar in cervantite. In many stibnite veins the lead content increases with depth so that jamesonite and boulangerite become abundant. In some veins the copper content increases with depth, as indicated by the presence of chalcostibnite and chalcopyrite. A striking feature of many stibnite veins is the presence of ferberite in pockets or veinlets, which are mostly later than the stibnite. Some stibnite veins, which contain gold both in the stibnite and in the quartz, change to gold quartz veins in depth. All veins thus far completely exploited change to barren quartz in the lowermost workings.

Gold Quartz Veins.—Epithermal gold quartz veins are found throughout the tin belt closely related to stibnite veins. The gold is irregularly distributed in the veins, and its ratio to silver is from 95 : 5 to 92 : 8.

Nickel Veins.—Nickel-bearing veins are common in the central and southern parts of the tin belt. The nickel arsenides, niccolite and gersdorffite, in some places with chalcopyrite, form small pockets in siderite and barite veins.

Copper Veins.—Veins of quartz, calcite and siderite containing chalcopyrite and tetrahedrite, are scattered throughout the tin belt. They are of slight economic value and have not been studied in detail. The change of antimony veins to copper veins in depth has been mentioned above.

ORE DEPOSITS OF GROUP B.

The deposits in this group range from the cryptobatholithic in which the intrusive rock relationship is fairly clear yet no intrusive rock has been found in the workings, through acrobatholithic in which the cupolas of the intrusions are just exposed, to the epibatholithic, in which large masses of the batholith are exposed and the ore deposits are peripheral to the batholiths. Only in the northern part of the tin belt are large portions of the batholiths exposed. In the central and southern parts the cryptobatholithic deposits predominate, for the presence of the batholith at depth is indicated by contact or thermal metamorphism of the sedimentary rocks, by presence of quartz porphyry dikes, or by the position, distribution and mineral content of the deposits themselves. In this group, zonal distribution of minerals is common, although influenced necessarily by the factors of original depth of the intrusion and depth of erosion, both generally unknown. Notable mines or districts are described briefly below as examples of the major groups, and the features of zonal distribution that they illustrate outlined.

Cryptobatholithic Deposits.

Condeauqui.[2]—This district, with its many mines, is unique in its mineral associations. The veins, which are mined for their

[2] Hess, F. L.: Some unique Bolivian tungsten deposits. Eng. Min. Jour. 112: 492–499, 1921; Ahlfeld, F.: Epithermale Wolframlagerstaetten. Bol. N. Jhrb. Min. A, B. B. 74: 1–19, 1938.

tungsten content, are in an anticline in Devonian shales and quartzitic sandstones. No igneous rocks are exposed, nor is there any evidence of contact metamorphism. The mineral content of the veins differs, but there is no regular pattern of distribution. The veins in the Ascension mine contain scheelite with barite and some stibnite; in the Juliana mine the ore consists of scheelite with ankerite and dolomite, and in the La Bomba mine scheelite occurs

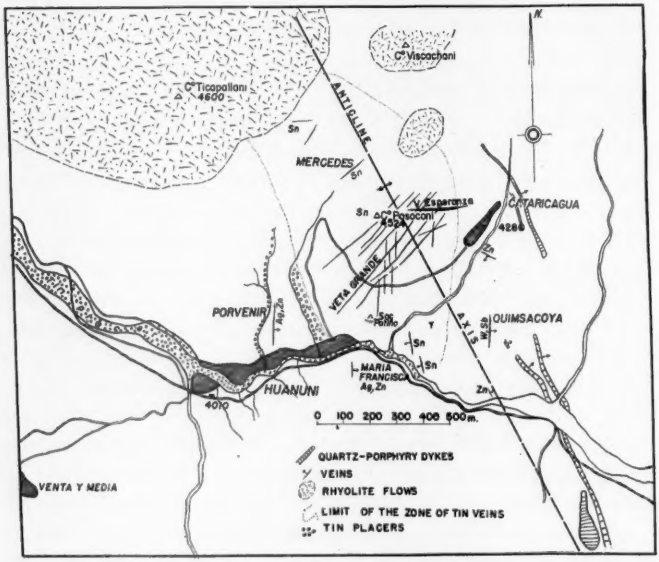


FIG. 2. Map of the Huanuni district.

with a large proportion of fluorite, calcite, ankerite and barite. Some small veins contain quartz with ferberite, in places associated with stibnite; others contain quartz with huebnerite. Tin has been found only in traces in some of the ferberite. All the veins decrease in mineral content with depth, to a maximum lower economic limit of 200 m. The veins are classed as epithermal.

Huanuni.—In this district (Fig. 2), Devonian shales and shaly sandstones are folded in a sharp anticline that trends north-

westerly. The sedimentary rocks are not thermally metamorphosed, but they are intruded by quartz porphyry dikes along the east side of the mineralized area and are overlain by later rhyolite flows. In the central part of the area is a group of tin veins that cross the axis of the anticline and extend 3000 m. parallel to the axis of the anticline and 1000 m. in width. Although oxidation is extensive, the primary ore where found consists of cassiterite with pyrrhotite, pyrite, black sphalerite, chalcopyrite, siderite, and some fluorite. Small amounts of wolframite have been found in one of the veins. The deposits are classed as hypothermal.

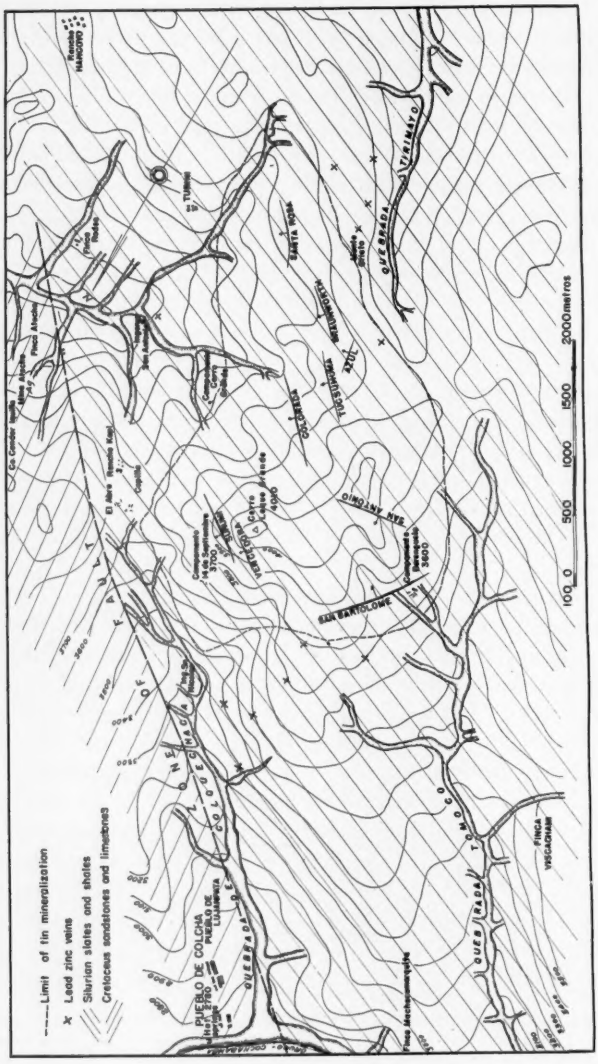
Outside of the tin zone are veins that illustrate lateral zoning. On the eastern side of the tin zone, in the Quimsacoya mine, the ore consists of chalcedonic quartz with stibnite and huebnerite. West of the tin zone, the veins in the Porvenir and Maria Francisca mines contain early sphalerite, arsenopyrite and pyrite and later jamesonite, boulangerite, galena, franckeite, cylindrite and needle tin. This zonal distribution shows that the sulphostannates, typical of the Bolivian tin belt, are later in the mineral sequence than the normal tin mineral assemblage and are epithermal.

Pucru-Amayapampa.[3]—This large mineralized area shows lateral zoning from hypothermal tin veins to epithermal gold-antimony veins. The deposits are in Devonian sedimentary rocks that show only slight contact metamorphic effects and contain no intrusive rocks. In the central part in the Italia mine, the veins contain pyrrhotite and cassiterite; in the northern part in the Pucru mines, the veins are of mesothermal type with sphalerite, pyrite and cassiterite. In the Vila Apacheta mine [4] on the eastern side, is an epithermal pyrite-cassiterite deposit in Cretaceous sandstone. To the southeast, the pyrrhotite-cassiterite veins change abruptly to the zone of gold-quartz veins of the Amayapampa mine, which in turn gives way to a long belt of stibnite deposits.

Colcha.—In this district (Fig. 3), a small elongate block of Silurian shales with northwest strike, has been thrust eastward

[3] Ahlfeld, F.: Typen boliv. Goldlagerstaetten. Zbl. Min. A, pp. 240–255, 1937.

[4] Ahlfeld, F.: Die Zinnerzlagerstaette Vila Apacheta, Bol. Z. prakt. Geol., 39: 33–38, 1931.


Limit of tin mineralisation
Lead zinc veins
Silurian slates and shales
Cretaceous sandstones and limestones
PUEBLO DE COLCHA
QUEBRADA DE COLCHA
QUEBRADA TOMOCO
QUEBRADA VIZCACHANI
SAN BARTOLOME
SAN ANTONIO
Pampa HANCOYO
Co. Condor Huilla
Mina Alcalde
Pacco Alcalde
El Alto
Rinconada Kasi
Campiña
Compañia Colcha Grande
Compañia Colcha Pequeña
Compañia Colcha Antigua
Compañia Colcha Nueva
Compañia Colcha Vieja

over Cretaceous sandstones and limestones. Although no contact metamorphic effects or intrusive rocks have been noted in the district, lateral zoning is clearly shown in the ore deposits. The large San Antonio and San Bartolome veins of the Berenguela mine in the central part show a normal mesothermal mineral group consisting of pyrrhotite, pyrite, siderite, ankerite and cassiterite. In the southern part of the area the several veins of the Cerro Grande mine are smaller and show a complex but variable mineral assemblage. The Colorada (Jatuncaca) vein of this group contains some pyrrhotite, pyrite, sphalerite, arsenopyrite, safflorite, cassiterite and minor stannite and franckeite. The Tucsuhuma vein consists of a breccia of ankerite, cemented by cassiterite. The Braunworth and Monte Cristo veins are transitional between the tin zone and the lead-zinc zone, in that they contain cassiterite with galena, siderite and tetrahedrite. The silver-bearing lead-zinc veins are mainly northwest and southeast of the tin area. A notable feature of this district is the occurrence of small pockets of niccolite and gersdorffite in the tin veins.

Colquiri.—The trunk vein of the Colquiri mine, now the second largest tin producer in Bolivia, consists of a large zone of mineralized fractures in Devonian sedimentary rocks. Contact metamorphic effects are slight at the surface but increase with depth. Two quartz porphyry dikes are cut by the main vein, which shows a normal hypothermal to mesothermal mineral assemblage, consisting of pyrrhotite, cassiterite, quartz, siderite, fluorite, and dark sphalerite containing admixed stannite. Galena occurs in the upper part of the vein, and wolframite has been noted in a few places. There is little change of mineral content with depth, except decrease in size of the vein and in the tin content.

There are few veins surrounding the main vein to show lateral zoning. The Inka mine 1 km. from the main vein reveals a quartz-fluorite vein with galena, sphalerite and pyrrhotite. A small vein 1400 m. south of the central part of the main vein consists of pyrite and marcasite with huebnerite and needle tin. 10 km. southeast of Colquiri, a large belt of stibnite-ferberite veins occurs in dark slates (Calacalani mine).

Chicote.—The Chicote district (Fig. 4) is on the prolongation of the trend line of the batholiths of the northern part of the tin belt. Although no granitic rocks are exposed in the district, a large mass of shale has been changed by contact metamorphism to

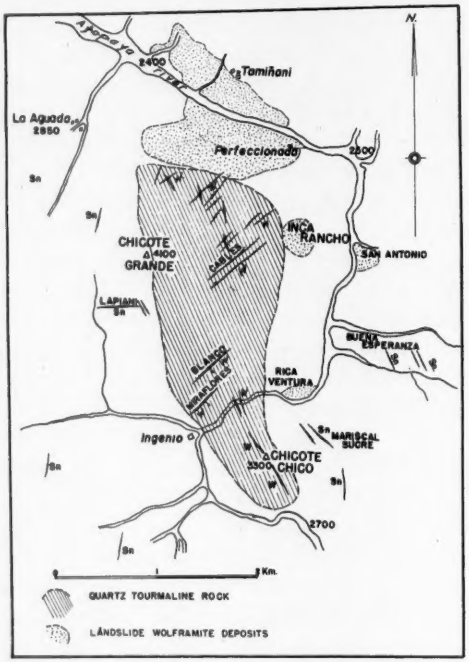


FIG. 4. Map of the Chicote district.

a quartz-tourmaline rock. Zonal distribution is well illustrated in this district in that the central metamorphosed zone contains a group of hypothermal quartz-wolframite veins with pyrrhotite and arsenopyrite, which have been exposed through a vertical range of 1000 m. Surrounding this central zone are pyritic tin veins of mesothermal type that reach to shallow depths only. There is no intermediate zone containing both wolframite and cassiterite.

The same kind of zoning occurs in the nearby Kami [5] and Amutara districts. In the Cerro Negro district on the southeast side of Illimani mountain, a central wolframite zone is surrounded by a zone of cassiterite-wolframite veins.

Tasna.[6]—In the Tasna area in the southern part of the tin belt, there is a large block or core of quartz-tourmaline rock of contact metamorphic origin in shale. Large quartz porphyry dikes in the quartz-tourmaline rock are cut by some of the veins. A quartz-wolframite vein, evidently formed at very high temperature as it contains a large proportion of plagioclase with pyrite, chalcopyrite and wolframite, occurs near the top of the mountain in the metamorphic rock. Near the boundary of the metamorphic core are the famous bismuth veins, which contain pyrrhotite, pyrite, wolframite, bismuthinite, dark sphalerite with admixed stannite, siderite, quartz and colorless tourmaline. Mesothermal pyrite-cassiterite veins with some tetrahedrite lie to the northeast in shales. It seems probable that a granitic cupola may lie only 800 to 1000 m. below the surface in the central part of the hill.

Acrobatholithic Deposits.

Chacaltaya.[7]—Here a small stock of porphyritic granite is exposed surrounded by a wide contact zone in which there are quartz porphyry dikes and a dike of siliceous tourmaline granite. The surrounding rocks are Devonian shales, although the Caca Aca batholith is not far distant. The lateral zoning in this area is different from that in districts where large intrusive bodies are exposed in that the pegmatites and the main tungsten zone are absent. Within the granite and metamorphic rock there are 45 veins that indicate temperature differences in their mineral assemblages or change laterally within the same vein in mineral content. One group of veins containing cassiterite, quartz, tour-

[5] Brehm, H.: Die Wolframit-Zinnerzlagerstaetten des Kami, Bol. Z. prakt. Geol. 29: 33–38, 1921.

[6] Ahlfeld, F.: Der Wismutberg Tasna. *op. cit.*, 40: 119–125, 1932.

[7] Lindgren, W.: The tin deposits of Chacaltaya. ECON. GEOL., 19: 223–228, 1924; Ahlfeld, F. and Muñoz Reyes, Die Bodenschaetze Boliviens, pp. 50–51, 1939.

maline and pyrite is believed to have formed at very high temperatures and to be of pneumatolytic origin. More normal hypothermal veins containing wolframite, cassiterite, black sphalerite, pyrrhotite, arsenopyrite and fluorite may change abruptly to mesothermal fluorite-galena-sphalerite veins (veta Plomo). At the border of the metamorphosed zone there are mesothermal cassiterite veins with chlorite and hematite, as in the Kala Uyu mine. The Rothschild vein of the Milluni mine is an excellent example of a mesothermal tin vein, with quartz, cassiterite, pyrite, sphalerite and barite. In the Kelluani mine a high temperature cassiterite vein is cut by a siderite-tetrahedrite vein. Siderite-galena veins occur in the outermost zone in the unmetamorphosed shales.

Other examples of acrobatholithic deposits around Cordillera Vela Cruz and Illimani batholiths have not been studied.

Epibatholithic Deposits.

The ore deposits around the margins of the large intrusive bodies of the Cordillera Real in the northern part of the tin belt in most places furnish good examples of lateral zoning. The cores of these batholiths are barren of mineralization.

Quimsa Cruz Batholith.—This quartz monzonite body, 45 km. long, plunges southward so that the northern part is deeply eroded, whereas the southern part is barely uncovered. Near the deeply eroded parts of the batholith, the main tin zone is gone, and wolframite-quartz veins are exposed in sedimentary rocks near the contact, chiefly on the eastern side. In the less deeply eroded central and southern parts of the batholith, tin veins of pneumatolytic origin occur within the granite. As represented by the veins of the Caracoles district,[8] these veins contain cassiterite, tourmaline, chlorite, pyrite and some bismuthinite, but from 150 to 200 m. below the surface the tin disappears and sphalerite becomes the dominant mineral. On the west side, a large zone of tin veins of pneumatolytic origin occurs in shales and quartzitic sandstones. These change westward into galena-sphalerite veins, as seen in the

[8] Lindgren, W.: Replacement in the tin-bearing veins of Caracoles, Bolivia. Econ. Geol., 21: 135–143, 1926.

Laramcota district. The outermost zone on either side of the batholith contains stibnite veins, many of them with gold. Veins in shales near Pongo in the Nueva Esperanza claim near the southern end of the batholith contain stibnite and cassiterite in intimate mixtures.

Two areas near the northwestern contact are of especial interest. At Araca, veins radial to the contact extend from the quartz monzonite into the thermally metamorphosed shales. The veins contain wolframite and arsenopyrite but cassiterite is absent; one of the veins contains molybdenite. Some 500 m. from the contact a parallel vein system in shales and quartzite contains a normal hypothermal mineral assemblage with cassiterite, tourmaline, pyrrhotite, chalcopyrite and pyrite (Viloco mine). Northward 6 km. from Araca, there is the following succession of zones:[9] First, a tourmaline-cassiterite vein (Barroscota mine) lies within the granite near the contact. In the sedimentary rocks near the contact are hypothermal wolframite veins with pyrrhotite, and further to the west are mesothermal cassiterite-chlorite veins near the village of Asiento. One of the veins (Carmen mine) contains large pockets of nearly pure jamesonite in quartz, with cassiterite, arsenopyrite and sphalerite. Here a zone of veins containing porous quartz with tourmaline and a little wolframite and scheelite is interposed between the usual tungsten vein zone near the batholith and the tin veins. Native gold is associated in this zone with later quartz pyrite and arsenopyrite (Rosario mine). This is an unusual zone in Bolivia.

Taquesi-Mururata Batholith.—This granitic body in the Cordillera Real near La Paz is 18 km. long in a northwesterly direction and 2 to 3 km. wide. It is deeply eroded, probably to depths of 3000 to 4000 m. As a consequence of the depth of erosion, the main tin zone is absent, and the wolframite zone is the most prominent.

On the eastern side of the batholith on Mururata Mountain, wolframite and scheelite occur in pegmatites in gneissic granite. Near the western contact close to Taquesi Pass, quartz-tourmaline

[9] Ahlfeld, F.: Typen boliv. Goldlagerstaetten. Zbl. Min. A, pp. 240–255, 1937.

veins with pockets of wolframite and some cassiterite (Andina mine) occur in the granite. A wide belt of metamorphosed shales and quartzitic sandstones occurs along the east side of the batholith in the Yungas region, and contains a number of tungsten veins, both near the contact and further to the east. The Chojlla

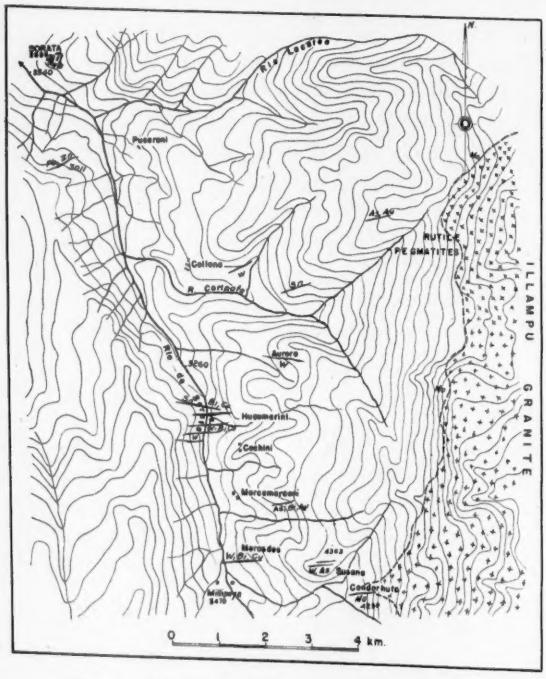


FIG. 5. Map of the Millipaya-Sorata district.

mine, one of the largest tungsten producers in Bolivia, includes a number of veins of pegmatitic type that contain very coarse cassiterite near the walls, and wolframite with quartz and arsenopyrite, pyrite, pyrrhotite and chalcopyrite in the central portion. The tungsten veins have a vertical extent of more than 1000 m. The veins of the Pichu and Enrramada mines in the highest part of the zone consist of quartz and wolframite without cassiterite.

At the southeastern end of the batholith, at the Bolsa Negra mine, flat-lying quartz veins with wolframite and some scheelite occur in tourmalinized quartzite. Silver-bearing galena and stibnite veins are in the next zone to the southeast, between Mururata and Illimani batholiths.

Sorata Batholith.—The Sorata batholith has a longitudinal extent of 40 km. in the direction of the Andean folding. At its southern end, on the eastern slopes of the Cordillera Real, there is a large area of tin-bearing pegmatites in granite and in metamorphosed shales that also contains molybdenite and lithium minerals, as in the Fabulosa mine. The pegmatites in places change to hypothermal veins, and contain large proportions of sulphides, particularly stannite, sphalerite and pyrrhotite.

Near Sorata (Fig. 5) at the north end of the batholith, the western contact is exposed over a vertical range of more than 3500 m. from the top of Ancohuma Mountain (6440 m.) to the river bed near Sorata (2500 m.). The deeply eroded core of the granite is barren, but rutile pegmatites and granite apophyses with molybdenite occur at the contact. Further from the contact, the metamorphosed shales contain magnetite veins and some gold-bearing arsenopyrite veins. Of particular interest is the big vein in the Marcomarcani mine that contains loellingite and arsenopyrite with some gold, cobalt and bismuthinite. A little tellurium occurs with the bismuth. Nearby, arsenopyrite and wolframite occur in a quartz vein of the Susanna mine. In the Mercedes del Illampu mine, a sulphide vein containing chalcopyrite, pyrite, quartz, wolframite, hematite, siderite and some bismuthinite is being worked. Parallel veins of Hucumarini show the same mineral assemblage but more bismuthinite. One of these veins changes to the west into a cassiterite-chlorite vein. The outermost zone near Sorata contains lead-zinc veins and a stibnite vein.

ORE DEPOSITS OF GROUP C.

Ore deposits are associated with 37 of the 55 small porphyritic stocks or volcanic necks within the tin belt. The elements are the same as those in the previous group, except that those found in

the pegmatites, Mo, Ti, Li and Nb, are absent, and silver is more abundant. Germanium is present in very small amounts. These deposits are believed to have formed from the same magma sources as those of the other groups. Consequently, it seems certain that the ore solutions came from great depths and not from the particular igneous body in which the ore is now found. There is no direct relation between the composition of the intrusions and the nature of the vein filling. The porphyry intrusions served only in providing channels for the ore solutions in their own fracture system and that induced in the surrounding sedimentary rocks. The mineralized area is thus limited to the porphyritic stocks or necks and the fractured rocks in the immediate neighborhood. High temperatures reached almost to the surface in some places, such as Chorolque and Llallagua, so that the normal hypothermal and epithermal zones are compressed into essentially the same zone. The term xenothermal, as used by Buddington,[10] best seems to describe these deposits. However, temperatures were very much less at other places, such as Oruro and Cerro de Potosi, and in these deposits zoning is more evident.

Cerro de Potosi.[11]—At this famous district, a group of veins in a small porphyry neck and in the surrounding sedimentary rocks contained, in their upper parts (4300–4700 m.), enormous quantities of silver sulphosalts with cassiterite and barite in some veins. A deeper zone (4000–4300 m.) contains cassiterite with sparingly distributed silver ores and stannite. Wolframite, bismuthinite, and a higher proportion of stannite and chalcopyrite appear in the deepest zone (3900–4000 m.) with cassiterite, but silver ores are absent. Veins outside of the central zone on the slopes of Potosi hill and on the Cerro Chico contain sphalerite, wurtzite, galena, sulphantimonides of lead and tetrahedrite. The workings in the central part of the Cerro de Potosi provide a section 800 m. deep.

[10] Buddington, A. F.: High temperature mineral associations at shallow to moderate depths. ECON. GEOL., 30: 205–222, 1935.

[11] Ahlfeld, F.: Neue Beobachtungen am Cerro von Potosi. Z. prakt. Geol. 43: 167–171, 1935; Evans, D. L.: Structure and mineral zoning of the Pailaviri section, Potosi, Bolivia. ECON. GEOL. 35: 737–750, 1940.

Chocaya.[12]—The main or trunk vein, known as the Colorada, was found in its southern part in the Animas mine to be oxidized and mainly barren to a depth of 75 m. From 75 to 230 m., the mineral assemblage is complex, and consists of rich silver sulphosalts, stannite, cassiterite, and pyrite as well as some bismuthinite with stannite and tetrahedrite in the lower part of the zone. Below the 234 m. level, the silver content of the vein decreases rapidly, and cassiterite-pyrite-quartz ore predominates; wolframite is absent. In the northern part of the vein, explored in the Oploca mine, the silver zone is not prominent, and although throughout the vein the tin content diminishes in depth, nevertheless, the vein in the deepest level of the Oploca mine, 650 m. below the surface, contains an average of 2 to 2.5 per cent tin.

The smaller Burton and Inka veins east of the Colorada vein contain complex silver-lead-zinc ores. The Animas and Arturo veins to the west of the Colorada contain zinc-silver-tin ores with franckeite. South of the Colorada vein in the Chocaya Grande district there are small lead-zinc veins with a high silver content that impoverish with depth.

Llallagua.[13]—In this, the greatest of all the tin deposits, the veins are concentrated in a volcanic plug or neck. Although hypothermal, mesothermal, and epithermal zones are largely superposed and differ from vein to vein, nevertheless, three zones can be distinguished in the vertical section. The zone near the surface is not abundantly mineralized, but contains such minerals as stannite, huebnerite, tetrahedrite, franckeite and galena. The next zone contains the very rich cassiterite ore shoots with bismuthinite and wolframite. Downward the tin content diminishes and the tourmaline content increases. Pyrrhotite and sphalerite occur on all levels. In the deepest level (775 m.), only small parts of two veins yield tin.

[12] Jaskólski, St.: Les gisements argento-stannifères de Chocaya en Bol. Arch. Min. 11: 25–102, Warsovia 1935.

[13] Ahlfeld, F.: The tin ores of Uncia-Llallagua. ECON. GEOL. 26: 241–257, 1931: The tin deposits of Llallagua. ECON. GEOL. 31: 219, 1936; Turneaure, F. S.: The tin deposits of Llallagua, Bolivia. ECON. GEOL. 30: 14–60; 170–190, 1935.

Pulacayo.[14]—This important district is notable in being free of tin, tungsten and bismuth. The upper parts of the veins are in dacite flows, whereas the lower parts, consisting in the main or trunk vein Tajo, are in sedimentary rocks. The veins within the dacite contain galena, wurtzite, sphalerite, sulphantimonides of lead, barite and a low silver content. The Tajo vein is pyritic and contains large ore shoots of silver-rich freibergite with sphalerite, galena and chalcopyrite. With depths the silver and lead content diminishes and sphalerite and chalcopyrite predominate to the deepest level, 800 m. below the surface.

SUMMARY.

These studies have shown that zonal distribution of minerals within the Bolivian tin belt is complex and differs materially from the ideal system of lateral and vertical zoning, as given by Emmons,[15] as well as from the zoning in the tin districts of Cornwall and southern China.[16]

The apomagmatic epithermal deposits of Group A, that is, those without any obvious connection with a magmatic source, contain the elements Sb, Zn, Pb, Ag, Fe, Cu, Ni, Se, W, Au and Hg. Sn, Bi, and Mo are absent. Although most of the antimony deposits of Bolivia belong to this group, the deposits as a whole are small and impoverish with depth. Vertical and lateral zoning are only slightly discernible, although the sulphide deposits change with depth to barren quartz or siderite veins.

The perimagmatic deposits of Group B, that is, those with an obvious or slightly concealed magmatic source, contain most of the tungsten and many of the tin deposits of Bolivia; and examples grouped under the headings of cryptobatholithic, acrobatholithic and epibatholithic are described. A wide variety of metallic ele-

[14] Ahlfeld, F.: Die Silber-Zinklagerstaette Pulacayo, Bol. N. Jhrb. Min. A, B. B. 75: 1–23, 1939.

[15] Emmons, W. H.: Relations of metalliferous lode systems to igneous intrusions. A. I. M. E. Trans. 70: 29–70, 1924.

[16] Wong-Wen-Hau: Les provinces metallogeniques de China. China Geol. Surv. Bull. 2: 37, 1920.

ments are contained, including Sn, W, Mo, Bi, As, Cu, Fe, Zn, Pb, Ag, Au, Sb, Li, Ti, Ni, Co, Te and Hg. Vertical and lateral zoning are well exemplified in this group. Taken together the vertical zones from the base upward are:

1. Zone of pegmatites containing tin and small amounts of W, Mo and Ti.
2. Principal tungsten zone, which in the deepest part is pegmatitic, in the middle part consists of quartz veins, and in the upper part is rich in sulphide minerals.
3. Principal bismuth zone, which contains sulphide minerals but is only locally developed.
4. Principal tin zone, which is hypothermal to mesothermal.
5. Principal zinc-lead zone with silver, which is mesothermal to epithermal.
6. Principal antimony zone, which contains stibnite, in many places with gold. The epithermal tungsten zone with ferberite, huebnerite and scheelite is closely connected with stibnite but occurs only locally.
7. Mercury zone, which is present in a few places but yields very little ore.

Copper ores are chiefly in zone 2, but there is no definite copper zone. Gold is found in hypothermal, mesothermal and epithermal deposits. It is not connected to a definite zone and it is almost always absent in tin and tungsten veins. Tin is found in zones 1 to 5 inclusive and rarely in zone 6. In zone 5, the tin in the form of cassiterite, with stannite and sulphostannates (teallite, franckeite and cylindrite), is with the sulphosalts of antimony and lead in epithermal veins. These mineral associations are probably due to superposition of the customary mineral zones. Nevertheless, such deposits reach only shallow depths. Transitions between zones 1 to 2 and 3, between zones 2 and 3 to 4, from 4 to 5, 5 to 6, and 6 to 7 are known. By no means does all this succession occur in the same vein, possibly for the reason that the cooling magma gave forth gases and fluids of different chemical composition at different times. Stibnite veins do not change in depth into tin or tungsten veins; the antimony solutions came

from the magma at a much later stage of cooling. Nor do the tin deposits of pneumatolytic type show transitions into tin pegmatites; they represent a parallel stage of ore formation at different depth.

In the deposits of Group C, associated with volcanic necks or stocks, the same ore elements are found as in Group B with the exception of Mo, Ti and Li, which are restricted to the pegmatites. Silver is abundant. Zoning is not so well shown in this group as in Group B, in part at least due to the superposition of zones. All these deposits " bottom " 600 to 900 m. below the present surface. In Potosi, the deepest zone contains Sn, W, and Bi, the middle zone contains Sn and Ag, and the upper zone contains Ag and Sn. The zinc-lead zone appears on the outskirts of the district. At Llallagua the usual zones are compressed.

As a practical deduction from this study, it is suggested that in deposits such as Huanuni and Colquiri, where the principal tin zone is exposed at the surface, it is possible that a tungsten vein zone lies 600 to 800 m. below the surface.

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DIRECCION GENERAL DE MINAS Y PETROLEO,
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OBSERVATIONS ON THE VEGETABLE CONSTITUENTS OF COALS.

WILLIAM C. DARRAH.

ABSTRACT.

The vegetable constituents of coals occur in complex organic mixtures that have been recognized by coal technologists and chemists as well as paleobotanists. However, the diverse interpretations and the nomenclatures involved in these different procedures have resulted in a confusion of data. The present communication presents a number of new observations on the banded ingredients of bituminous coals and their combustion properties, particularly with reference to low temperature carbonization. It is believed that the results are of significance both in the utilization of low-grade bituminous coals and in the academic investigation of the problem of the origin of coal. It is suggested that all plant tissues and products contribute to coal accumulation and that the controversy over the lignin or cellulose origin of coal is without meaning.

PALEOBOTANISTS have had a dual interest in the study of coal and other carbonized sediments: the origin of coal, and the properties of the various coal constituents. The vegetable origin of coal is now universally accepted, and it is difficult to conceive how serious opposition to this concept ever gained adherents. Hutton, before 1830, had demonstrated that translucent slices of British coals revealed unmistakable plant remains. By 1840 Goeppert had undertaken both botanical and chemical studies on the nature and origin of coals. Following this early period of coal technology there developed a long and almost fruitless controversy concerning the geological origin of the fossil fuels, particularly with reference to their origin in place or their transported origin. During the 19th Century, coals were employed extensively for industrial purposes, but it was soon learned that the various kinds of coals performed differently in these industrial processes. "Steam," "gas," "coking," and "non-coking" coals received their names during this period.

More recently the importance of the coke and by-product coke industries initiated a new field of coal technology. The demand for special coals focused attention on the constituents of coal and the chemical derivatives that could be recognized by distillation. Concurrently, along entirely independent lines, paleobotanists (4, 5, 24, 45) * proposed an involved terminology intended to describe not only the varieties of coal and related sediments, but also the ingredients that could be determined. Few attempts have been made to correlate all of these diversified interests and to summarize present trends in the investigation of the composition of coal. In England, Wheeler and his colleagues attempted to ascertain the chemical behavior of the more obvious components of banded bituminous coals. In the United States, Stadnichenko (42, 43, 44) has been able to make accurate determinations of the combustible properties of many carbonaceous sediments with ingenious apparatus of her own invention. In Germany there has been a considerable school of coal technologists, though only Potonié (32) can be regarded as primarily concerned with paleobotanical aspects. Fischer (10) and a number of collaborators have made important contributions in the biology and chemistry of coal.

CONSTITUENTS IN THE COAL MIXTURE.

Stopes (45) devised a convenient nomenclature to designate the ingredients of banded humic bituminous coals. These terms have become so well known that the limitations of their usage are seldom considered. They do not apply generally to post-Paleozoic coals but so far as is known apply only to true bituminous coals. Certain of the terms, however, refer to structures of fairly wide distribution and can be used to describe analogous constituents in peats, brown coals and anthracites. Brief definitions of the four banded ingredients as they conform to modern usage are as follows:

VITRAIN, a colloidal mixture entirely without structure that seems to soak up all of the other components of coal and serves as a binding material. It is translucent and uniform and thus likely a solidified gel. It

* Numbers refer to bibliography at end of paper.

occurs also in thin bands which may split up into small cubes or angular fragments. The ash content is low, rarely exceeding 1.2 per cent.

DURAIN, a fine granular substance or mixture that breaks with an irregular fracture. It is tough and firm of texture. Microscopically it is a fine conglomerate composed of minute plant parts which are soaked up and held together by vitrain. The ash content is moderate to high, rarely 7 per cent, more commonly 5 to 6 per cent.

CLARAIN (-Telain), these are larger fragments of plant tissues, such as wood, stem, leaf tissues and other recognizable parts. These are always soaked up with vitrain, which not only fills the cell cavities, but also impregnates the cell walls. The ash content is low, varying from 1 to 1.75 per cent.

FUSAIN, is black, opaque and always shows the skeleton of cellular structure. In other words they are fragments of plant tissues that show the character of charcoal. The ash content is high, average about 15 per cent.

The term durain is of doubtful validity, in that it refers to a mixture composed of finely divided plant debris soaked up with vitrain and held together by it. Therefore it would seem more accurate merely to call it finely divided debris, which in practice does not admit detailed description. Macerated durain upon drying in air yields a fine brownish palpable dust. Gradations between two or more ingredients or structures are sometimes given independent designations but these do not add to the clarity of the classification.

Two of the banded ingredients show clearly the cellular construction of woody plants: fusain and clarain. The materials were therefore derived from the same kinds of plants and the same parts of plants, but some differences in decomposition and preservation have taken place.

There is little agreement among specialists regarding the origin of fusain. The view now generally held is that fusain is the result of subaerial oxidization that takes place after burial of the debris. David White (54) and others have shown convincingly that this is most probable and can be duplicated in the laboratory. In many coal balls one side of a plant fossil is fusainized while another is not. Furthermore, there is no evidence that this carbonization is in the form of burned tissue. Fusain occurs not only in

banded bituminous coals but also in peats, lignites and anthracite. It is non-coking, being already devolatilized, and does not ordinarily influence the coking behavior of the coal. However if the fusain content is high (exceeding 15 per cent of the bulk of the coal), the coal is " non-coking." at high temperature carbonization, although it may be " coking " at low temperature carbonization. The clarain represents those plant tissues that have not undergone the same order of oxidation and therefore have retained more of their volatile ingredients than the fusain, although from the standpoint of botanical origin there are no points of difference. Many specimens of coal ball plants show a peculiar characteristic red-purple color, which is an intermediate stage between fusain and clarain. However, this alteration or condition does not in anyway distort the volume nor the configuration of the cells present. Tracheids of the seed-fern stem known as *Medullosa* which have been fusainized can be recovered in many macerations of coals and coal balls.

Vitrain exerts a great influence on the properties of a particular coal. In those coals in which it is abundant there is a relatively high gas and aliphatic hydrocarbon content. It aids in the formation of coke, provided that a considerable quantity of woody clarain (anthraxylon of Thiessen) is also present.

Thiessen (49) proposed the name anthraxylon for the bright bands in bituminous coals which are composed chiefly of clarain (telain). The bright bands are flattened pieces of stem and other woody tissues, which often reveal striking microscopic structure. The durain is the detritus (in part) of Thiessen and, in his interpretation, is of secondary importance in determining the variety of fuel for industrial use.

These four ingredients react differently under pyrolysis. The vitrain begins to fuse, liquify and volatilize at a temperature between 50 or 70° C. This accelerates and by 230° has continued until the coal sample shows an appreciable loss in weight. At a slightly higher temperature the durain commences to flow and compact, chiefly because the binder is vitrain. At temperatures between 350 and 450° the clarain commences to disintegrate, the

cells break down, lose their identities and the tissues display a marked tendency to swell apart (intumescence) indicating that more than one material is present in the wall. At higher temperatures (above 600° C.) there remain skeletons—more or less structureless—composed of carbon with an exceedingly low volatile content. This residue is " coke " or its amorphous equivalent.

Turning now to the structure of such true coking coals as those from Connellsville, Export, and Pittsburgh, the three from western Pennsylvania, and the Pocahontas coal from Virginia, each shows a similar mixture of the banded ingredients. All four coals are woody, bright-banded varieties with a reasonably high proportion of spores and pollens, which despite their collapsed nature, are large, translucent yellow or orange bodies. In addition in all four coals there are numerous resinoid bodies that cannot be identified with particular plant structures. If a thin section is prepared from such a coal and cemented down to a glass slide with sodium silicate, it can be demonstrated by application of heat, that the first structures to undergo destruction at low temperatures are the spores and resinoid bodies, which swell, burst, and undergo complete volatilization, leaving empty porosities in their places. A coal rich in these constituents, if properly heated, will release rapidly a large amount of volatile materials derived from spores and resinous bodies, giving a characteristic sponginess to the coal. This condition will be enhanced and increased as the woody materials likewise lose their volatile fractions. If comparison is made with a cannel coal, which is composed chiefly of spores and pollen grains, a remarkable contrast is evident. The spores on the periphery, i.e. on the exposed surface of a piece of cannel coal, swell and rupture almost at once. Those adjacent volatilize next and as this proceeds the whole coal shrinks and forms an amorphous powdery mass, which occasionally shows a tendency to fuse.* Since there is no vegetable ingredient in the cannel coal with a high volatilizing temperature, no organic skeleton of carbon is present and therefore the coal is a non-coking coal. This observation is not entirely new, but it was a source of a con-

* Due to the presence of " ash " with low fusibility.

troversy a decade or so ago. From his many microscopic investigations of the paleobotany of coal, Jeffrey (19, 22, 23) had concluded that the woody tissues present in the coal determined whether a coal was coking or non-coking. However, most of the true woody lignites are non-coking and a great number of woody coals of bituminous rank are poor coking coals. Thiessen believed that the spores determined the coking property to a considerable degree, although he pointed out carefully that too high a spore content rendered a coal useless for coking purposes.

Thus, the so-called four coal constituents have considerable individuality chemically, structurally and botanically, and have a profound influence upon the properties of the fuel.

It is necessary in passing to indicate that any such classification with a small number of entries is over-simplified, and takes on a high degree of artificiality. It serves a very practical purpose, however, by presenting in elemental terms the general characteristics of the material at hand. The microscopist is able to recognize these four banded ingredients. The coke producer and coal chemist employ instead a terminology based on chemical compounds and their distillate fractions such as "coal gas," light oils, heavy oils, ammoniacal liquors, green oils, etc. The paleobotanist in contrast recognizes not only a foundation for the banded ingredients, but he can go so far as to identify the individual kinds of plants, their tissues and organs, and in many cases their chemical constituents. Thus, in his estimation the other classes of nomenclature are but approximations. They are purely pragmatic.

ANALOGOUS CARBONACEOUS MATERIALS AND THEIR DERIVATIONS.

It has been known for a long time that there is a close analogy between the formation of coal and the formation of "carbonized impressions" of a fossil plant. Indeed, the term carbonized impressions has been shown to be so inappropriate and of such rare occurrence that various new names have been proposed. The term "mummification," is used by many paleobotanists with the definite connotation that the plant body is preserved by partial

alteration of the plant itself. Older investigators have applied the name " coalified impression " for this same type of preservation. Any microscopic study of a coal sample, with the possible exception of certain anthracites, will prove at once that coal is comprised in large part of modified, partially destroyed, plant structures. Treatment with strong macerating fluids will remove the mineral matrix or " ash " and set free the more resistant plant parts. Similarly an impression of the mummified type, if placed in a strong macerating medium, will also become so altered that certain plant tissues, notably cuticles, spores and vascular elements, may be removed and studied under a microscope.

Earlier mineralogists placed coal and related natural occurring carbonaceous materials at the end of their " system " and although recognizing a great variability in the chemical constitution of coals, merely distinguished many varieties based chiefly upon optical properties. They did point to several variable features of these materials. First and most important are the proportions between carbon, hydrogen and oxygen; thus if one studied the various forms of sediments from peat through lignites, thence bituminous coals and thence to anthracite, one would follow an increasing carbon content and conversely a decreasing hydrogen and oxygen content. This ultimate analysis based on the proportions of the elements present did not aid much in recognizing the differential behavior of coals for industrial use. Later it became the practice to distinguish as well the ratio between so-called " fixed " carbon and volatile materials and this gave rise to one of the distinctions between coking and non-coking coals. With the development of the chemical industry, the discovery of natural petroleum and the development of the by-product industry, a great deal was learned incidentally concerning chemical constituents, or at least those chemical substances that are derived from bituminous coals by distillation.

There are two fundamental methods for the distillation of coal, both of which may be accomplished by varying procedures. The most commonly used in industry is the destructive distillation or high temperature thermal-decomposition of coal (31). By this

method large quantities of relatively simple hydrocarbons and other materials can be recovered. It has been known that this treatment of coal with high heat (1100–1300° C.) increases the yield of gas and of the so-called gasolines. The term "increases" here means that by fractional or low temperature distillation much less gas and low volatilizing oils are obtained. The coal in the second method is subjected to heating, beginning at approximately air temperature and then very gradually increased until a semi-coke or otherwise carbonized residue remains in the retort. In most coals gas is evolved immediately upon heating and the first drop of liquid occurs somewhere between 45 and 50°; many times, however, the first drop occurs near 60°. Both methods of distillation yield approximately the same products, the chief difference being the relative proportion of the different classes of distillates obtained by the two methods, particularly the quantity of gas and gasoline and the composition of the pitch and coke. Gas evolved at low temperatures is known as "coal gas" and has been found to be composed by simple saturated hydrocarbons, of which methane is a common ingredient. The next fractions are light oils, the so-called gasolines and kerosenes, which accumulate between 85 and 350°. This fraction contains a great variety of substances. Between 450–500° the coal for the first time shows a fundamental change in its appearance. The coal becomes swelled, is filled with many porosities and shows the effects of the liberation of the low volatile ingredients. A partially distilled sample, if treated with maceration fluids, shows at once which of the plant constituents have been most altered by the heat. This point will be considered in more detail below.

Since coal is the accumulated debris of plant organisms the organic components of coal are the direct derivatives of the decomposition of plant products. In the plant body almost all of the organic compounds are highly complex (carbohydrates, lipins and proteins). Hydrocarbons may occur although they are insignificant in proportion to the other three classes. Thus there is an interesting distinction which presents itself at once. The proportion of hydrocarbons in the plant body to those in coal is very

disproportionate and one cannot often recognize as such the typical proteins, lipins and carbohydrates in coal. Thus, all of the complex organic compounds have undergone greater or lesser destruction. The chemistry of coal is a highly controversial problem (2, 12, 38, 48). There are three major schools of thought. First, in coal there are a great number of different chemical substances that occur distributed more or less evenly in a colloidal system and that by treatment with solvents such as petroleum ether, pyridin, analine, etc., one may recover some of these constituents. Furthermore, by fractional distillation one can recover a still greater variety of those materials present in the coal in essentially the same form that they occur in the coal. The second school of thought is somewhat more indefinite. Coal is regarded as a colloidal mixture but with relatively few complex ingredients, which tend to decompose rapidly upon the application of heat and thus we merely recover a great number of simpler substances with smaller molecules, as the more complex undergo transformation and decomposition. This school of thought holds that little is to be gained by the study of individual substances recovered by solvents or fractional distillation. The proponents of the third school believe that there is a definite coal molecule, which may, however, occur in varying proportions in the several kinds of coal.

It is known that with the increase in the temperature employed in distillation, there is an increase in the yield of simple hydrocarbons, so that some destruction even at low temperatures certainly occurs.

There has grown up within recent years an ill-founded controversy over the primary constituents and chief contributors to coal formation. Some hold that in the progressive carbonization of sediments from a peaty condition to coal, the cellulosic materials undergo continued hydrolysis and therefore the lignin component produces the bulk of the carbonaceous materials present in the coal sediment (13, 14, 32). The lignin being less rich in oxygen produces, under normal circumstances, humic material upon decomposition. It is argued that living wood contains more

cellulose than woods accumulating as peat, and furthermore in true lignites the lignin content is proportionally still greater. Mitchell and Ritter have shown (28) that in certain Miocene woods from the auriferous gravels of California, a notable cellulosic content is still present although proportionately it has become unimportant. Other investigators hold that the cellulose and not the lignin, is the primary contributor to coal formation and a large body of experimental fact has been brought to bear upon this theory. Of recent investigators Berl (2, 3) has produced the most convincing results, which involve high temperatures and high pressures to bring about the conversion of many pure carbohydrates into " coal," " asphalts," and " petroleums."

The cellulose-lignin controversy is really meaningless because any microscopic investigation of coal will reveal the presence of diverse plant parts, some of which are entirely non-woody and have neither cellulose nor lignin. Nor can structures like spores, pollens, waxes and cuticles be interpreted as having been derived from cellulose or lignin. In the so-called paper coals, cuticles comprise nearly all of the coal bulk (55). Spores form the cannel coals, (1, 54) and putative algae form torbanites, oil shales, bogheads and many other canneloid sediments (18, 58). Every coking coal contains a large proportion of spores (6, 35, 36, 47, 50). Thus as Gothan (15) argued many years ago, all of the plant products contribute, certainly unequally, to the end product that we call coal. To ascribe to any single class of organic substances the responsibility for the whole carbon content of a coal is to speak with prejudice.

This is not said in criticism of the significant results obtained by Berl (2) a proponent of the cellulose theory, nor of Fuchs, (12) a proponent of the lignin theory, nor of any other workers who have approached this problem from non-paleobotanical standpoints. Berl cautions that many of his suggestions might not find acceptance among geologists and that he has obtained his results purely from the approach of experimental chemistry.

Still more evidence suggests that there is not yet a basis for agreement and understanding in the problem of the nature of coal.

The presence of detectible porphyrins (51), spores, and low volatilizing chemical substances in coal confirms the belief that high temperatures were not associated with coal formation during geologic time. This is even true of anthracites where the plant structures, such as spores, are still present, as Turner (52), Hseih (17) and the writer have previously described. Every evidence points to the fact that anthracite coal is really a "set" colloid that behaves as a polymerized plastic substance. One may draw a crude analogy between anthracite coal and bakelite. It is a significant fact that anthracite coal has not undergone any appreciable loss in volume, during its carbonization, nor have the plant tissues present undergone compression or distortion. An anthracite coal bed, except where it has been squeezed and has yielded in a fault or syncline, is no more distorted or crushed than a bituminous coal. The alterations are physico-chemical rather than purely chemical. Although real understanding of the nature of the coal problem must come from chemists who can best determine the manner in which the many ingredients are associated and combined, no fundamental progress can be made until something of the coal mixture has been understood.

Three of the recognizable plant constituents of the soft bituminous coals are directly related to the release of smoke in the combustion of the fuel in industrial and domestic purposes. The spores, which volatilize at low temperatures, produce a yellow flame, liberating a considerable amount of heat. The spore component in the absence of abundant air cannot be oxidized completely. Therefore, much of the volatilized residue is only partially burned, and is ejected from the flue as finely divided flocculent soot which will leave a greasy smudge because of its high oil content. Secondly, as the spores are volatilized much of the finely divided carbonaceous material, which is present in the durain, is driven off in an unconsumed manner by the rapid evolution of gas. Finally, the vitrain behaves much as the spore content in that it volatilizes rapidly and gases are evolved with such volume that they are not consumed in the firebox. Consequently much of the high heat ingredients is lost and dissipated.

This initial loss is augmented by the detrimental effects of soot and coal dirt.

INORGANIC CONSTITUENTS.

Various inorganic constituents recognized in the ash indicate a direct relationship to the original plant bodies, although admittedly one must analogize between living plants and fossil plants for an explanation. The amount of sulphur in coal of all varieties is of such high proportion, relatively speaking, that it must be in part derived from organic sources. The amount of sulphur in the coal is invariably higher than in the underclay beneath the coal and the shales ("slates") above the coal. Thus the source of sulphur is primarily one of simultaneous origin. The sulphur that can be recognized mineralogically is in the form of sulphides, such as pyrite and marcasite, or more rarely in the form of sulphates, such as gypsum. The pyrite occurs in two forms: the more obvious as the large crystals or crystalline masses visible to the naked eye, scattered between the cracks and crevices and partings in the coal; the less apparent as fine particles in the plant tissues. These minute particles or granules can be observed in thin sections or polished surfaces of coal when subjected to magnification of about 100 times. The grains occur irregularly but abundantly in plant tissues, particularly in cell walls. *No washing process can free the coal of this minute-grained sulphur component.* If one compares the mineral sulphur with the total sulphur obtained by ultimate analysis, there is still a discrepancy. Thus, this difference is most likely in the form of complex organic substances. The relatively high proportion of ammoniacal liquor and other nitrogenous materials that are recovered from coal, attest to this fundamental fact. Likewise considerable portions of the iron, magnesium, and other elements are probably derived from the original proteins present in the plant bodies which compose the coal.

MACERATION EXPERIMENTS ON COAL CONSTITUENTS.

To return now to the mummification of "coalified" impressions some explanation can be seen for the occurrence of plant tissues

as a thin, greatly compressed plant body. A simple experiment serves as a demonstration. A specimen, for example a fossil leaf, is freed from as much of the surrounding rock matrix as possible, and placed in a vessel containing Schultze's mixture. Within several days the fossil will either float free from the rock or be so loosened that it can be removed easily with a knife or other sharp instrument. The plant body thus removed has a relatively high tensile strength. It can be lifted, bent slightly, twisted very slightly and otherwise subjected to torsion movements. Considerable bending, however, will always result in a sharp break in the body. Occasionally, the macerating fluid will be stained brownish or reddish, although this is not always the case. If the plant structure is now washed with distilled water and then alkali (sodium or potassium hydroxide) is gradually added until there is a strong concentration, the solution will become rapidly discolored brownish to a deep reddish, until the plant body dissolves, almost completely, leaving behind only those plant tissues that are cutinized (the cuticle of the leaf and spores which were borne upon the leaf or which were adhering to it). Sometimes, though not always, a few of the heavy-walled cells of the conducting tissue also remain. The residue that remains is still a complex mixture of organic substance of undetermined composition—certainly not free carbon.

Recently, through the discovery of well preserved plants in coal balls from Iowa and Kansas, there has been found a means of isolating, in relatively pure fashion, a considerable number of plant structures and it has been ascertained that they are the same as the ingredients in the neighboring coal. Recent investigations (7, 25, 26, 21, 40, 46), have shown clearly that the plants in coal balls are a fair sample of the plants in the coal surrounding the coal ball. My own published investigations on this point are in agreement with those previously published. Three different methods have been applied to the recovery of recognizable plant structures in coal balls. The first method is that of grinding thin sections, which can be made sufficiently thin to render the specimen thoroughly translucent. This method produces no chemical

change in the ingredients of the coal ball, the thin section being ground upon a revolving wheel with abrasive powders, with a constant flow of cold water to maintain a low temperature and prevent the volatilization of any of the solid portions of the coal ball. It must be noted, however, that during the grinding of the coal ball one may often detect the odors of methane and related hydrocarbons and of hydrogen sulphide. How these are set free unless they are merely occluded gases, is a question I am unprepared to answer. The most abundant liberation of such gas mixtures are observed in Belgian coal balls, where the fetid odors can be noticed many yards away from the grinding apparatus.

The thin sections of the coal ball reveal a considerable amount of information. The plant body is self-evident by the cellular tissues, which are not destroyed. The cell walls are occasionally frayed slightly although usually they are remarkably perfect. The middle lamella is most often gone, leaving a clear line of demarcation between adjacent cells. Fine particles of pyrite are scattered throughout the plant tissue. These are microscopic in size although they glisten in reflected light. The mineral matrix, which is mostly calcium carbonate and iron pyrite in Iowa coal balls, has indurated in an amazing fashion. Growth of the crystals seems to have commenced at the cell wall and proceeded away from the wall. Crystals do not penetrate or transgress through the individual cells. Within the cell cavity the mineral has formed as from the cell wall and built towards the lumen, gradually filling the entire cavity. Thus the cell walls and in fact the whole plant structure is embedded in mineral. The spores and pollen grains in the coal ball show globules of "oil," although in solid form. The spore and pollen grain membranes have a bright yellow color, amber-like in appearance; they are never mineralized. Occasionally large fragments of fusain, always retaining the construction of some plant body, can be recognized.

Thus far the recognizable plant structures and their distribution in the unaltered coal ball have been considered. No treatment to which the specimen has been subjected has modified appreciably these materials. The second method, the nitrocellulose peel

prepared from a smooth or polished surface, is of interest also, because at most the amount of destruction that results is insignificant. This method has been repeatedly described * and details of the procedure need not be repeated here. Briefly, however, the surface of the coal ball is etched with 5 or 8 per cent solution of hydrochloric acid and then washed with gently running water. After the etched surface has dried a solution of cellulose nitrate in butyl acetate is applied to it. When the solution has hardened it leaves a thin film that can be peeled off, bringing with it a perfect replica or transfer of the plant tissue in the coal ball. The mechanism involved is fundamentally very simple. The mineral material, especially the calcium carbonate, is dissolved by the acid and the soluble salts are washed off. Small particles of pyrite, even though they are not dissolved, are loosened and these too are removed by the running water. On the other hand the organic remains are inert to dilute hydrochloric acid, or to any other dilute inorganic acid, and therefore the plant structures stand out in relief upon the etched surface. The solution of nitrocellulose merely surrounds and embeds the exposed plant structures, which later are pulled off with the peel. The preparation of more than a hundred thousand peels in this laboratory has yielded convincing evidence that such preparations do not seriously distort the tissues thereby transferred. The plant structures obtained in the peels show that the materials occur as in the thin section of coal, except that they are demineralized and there is greater transparency. This is in part due to their extreme thinness. A good peel removes only 1 to 2 micra of the original specimen. The cell walls are brown in color, but the color varies considerably from locality to locality. The cell walls are sometimes distorted although this is always a matter of preservation and not of treatment. The spiral thickenings on many of the tracheids are evident. The spores and pollen grains appear as bright objects, often revealing contents of cellular nature. Spores can be liberated from the peel by redissolving the cellulose nitrate. Occasionally pieces of wood or other plant structures show purplish-black or color characteristic of

* See the writer's Textbook of Paleobotany, New York, 1939, Chapters I and IV.

fusain, and such structures do not admit transfer without breaking. In other words the plants have been altered during preservation. The chemical treatment involved in the peel method is so moderate that no distortion or destruction of the tissues takes place. The fine particles of pyrite that were present in most of the cell walls are still to be observed and they have not been removed by the dilute hydrochloric acid. Peels can be prepared from coal by a simple modification of this technique.

The durability and relative indestructibility of many plant structures in coal balls and in coalified impressions seemed to be worthy of further investigation and experiments involving the complete maceration of the coal ball with dilute acid over fairly prolonged periods of time were commenced three years ago. The idea is simple: if a small quantity of the matrix can be removed with 5 per cent hydrochloric acid when the surface of a coal ball is etched, then prolonged treatment with the same concentration of acid, if supplied in ample quantity, should ultimately remove all of the mineral matrix. A small coal ball, approximately a 2 inch cube, can be macerated completely in about 48 hours. The plant structures liberated from the matrix behave in varying fashions. Many of the leaf-fragment, spores, and other miscellaneous debris float to the top of the solution. The fragments of wood and other dense tissues sink to the bottom and accumulate in the sludge. The sludge also contains a fine powder of pyrite crystals, miscellaneous finely divided carbonaceous waste, and the insoluble mineral constituents. In many samples a thin film of oily material floats upon the surface of the solution.

The individual plant fragments exhibit a high degree of individuality, with respect to optical and chemical properties. Furthermore, they may be identified by paleobotanical means and can be compared with allied plants. The spores recovered from coal balls turn color upon heating at 130° C. and have volatilized, except the spore exine, by 255° C. These behave therefore as vitrain. Fusain is fairly abundant in the coal balls, but upon maceration, disintegrates to amorphous fusain residue and loses its cellular identity. As yet the techniques of microchemistry

have not been applied in an attempt to localize the different organic materials that can be recovered by distillation of the coal and relating them to plant constituents.

Not all of the so-called ingredients of banded humic coals can be recognized as such in the coal ball. It would seem that biochemical decomposition in the coal has advanced to a far greater degree than in the plants present in the coal ball. However, this may be illusory. The frequence of the plant debris in the coal ball is far less than in the coal itself and the binder in the coal ball is always an inorganic salt or a mixture of salts, whereas in coal itself it is clarain. In many coal balls, as in many coals, there are large masses of "waxes" and "resins," which are essentially mixtures of hydrocarbons. It is very probable that these are vitrain and merely occur in irregular masses rather than in a more diffuse condition.

CARBONIZATION EXPERIMENTS.

It would appear, therefore, that there is a practical significance of plant structures in dull low-grade bituminous coals. It is generally assumed that the low-grade bituminous coals of the interior coal basins of the United States are non-coking. Most experiments of these coals have been carried out with the view of determining whether a coal will produce metallurgical coke and therefore the results do not necessarily imply that cokes produced by low temperature treatment could not be formed. Nevertheless it has been determined (11, 29, 30) that certain Iowa coals could be subjected to pre-heating and then carbonized to produce a fairly satisfactory material. Similar experiments have been carried out in many laboratories. In my laboratory a number of small samples of coals from Iowa, Missouri, and Kansas, of known paleobotanical constitution were carbonized at temperatures varying between 450–550° C. All of these were subjected to pre-heating at 150° C. for thirty minutes. Samples were taken at the termination of pre-heating and macerated in Schultze's fluid, in order to see what transformations in the components of the coal could be recognized. In every case the total loss of weight

was less than 12.5 per cent and the only alterations were in the general porosities of the coal. Spores had not yet lost their identities although in some cases they seemed to have wrinkled appreciably. The vitrain did not seem to have undergone any fundamental change except that it had changed color slightly and became darker. The specimens that had been pre-heated were then heated to 500° C. and the product subjected to maceration. By this time all of the spores had disappeared, the vitrain had been volatilized except for a few clear resinoid bodies that occur as irregular masses of small size, and the coke-like product is not black, but has a peculiar purplish-brown to steel-grey luster. This material still has a relatively high volatile content. From our limited quantities it would appear that this is a very variable content.

There have been so many experiments on the low temperature carbonization of coals to produce smokeless domestic fuels that there is no need to consider these methods here. From a paleobotanical standpoint, however, it is highly significant that preheating a dull bituminous coal with high spore content for a short period of time prior to carbonization will result in a superior end-product and the detrimental influence of the high volatile spores can be, to a large extent, circumvented by the gradual volatilization of their contents.

SUMMARY.

1. The nomenclature based upon the four banded ingredients (vitrain, durain, clarain and fusain) of humic bituminous coals is accepted for conventional purposes. It is shown, however, that these are not petrographic, chemical or botanical components, but instead are in themselves complex mixtures that exhibit remarkable individualities chemically and physically and therefore behave differently in carbonization processes.

2. Coal is considered to be a mixture composed of: (*a*) a considerable amount of recognizable plant fragments showing microscopic cellular construction—these are relatively unaltered and may even exhibit both lignin and cellulose derivatives in the same

cells; (*b*) a small amount of mineral in the form of ash derived in part from the original plant tissues; and (*c*) a considerable amount of waxy material in a colloidal mixture rich in hydrocarbons which serves as a binder (vitrain) for the coal matrix and soaks up all of the other constituents of the coal.

3. Recent studies based upon organic remains in coal balls from Iowa and Kansas show that these are true petrified coals and that the plant parts may be recovered and demineralized and later subjected to chemical investigation. The plants within the coal ball are identical with those in the associated coal. However, the banded ingredients of coal cannot be recognized in the coal ball. Therefore it is suggested that the vegetable debris in coal has undergone greater alteration than those plants embedded in petrifying minerals.

4. It is shown that all plant parts and products may contribute unequally to the end product, which is the coal. Therefore, the controversy over the supposed cellulose or lignin origin in coal is without significance from the standpoint of the geological origin or the chemical derivation of the organic compounds present.

5. Fusain or mineral charcoal occurs abundantly in coal and in coal balls. Any plant part can be fusainized and this renders untenable the opinion that only structures derived from lignin produce fusain. Fusain, because of its devolatilized condition, is non-coking. However, under low temperature carbonization it does not modify the coking property of the coal, although under high temperature carbonization process, it prevents the normal formation of coke, chiefly because it crumbles to finely divided dust.

6. Coals with a high spore content yield corresponding high quantities of gases and low volatilizing oils even at very low temperatures. Such coals, contrary to common belief, can be carbonized to yield a coke-like product (semi-coke), provided that they are first subjected to pre-heating in order to liberate much of the gas and aliphatic hydrocarbons.

7. Since no two coals can be expected to contain the same proportions of these ingredients and the same coal varies in the

proportion between these ingredients, it is apparent that a proper understanding of the coal mixture may be of considerable significance in the investigation and utilization of many fossil fuels.

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THE DIRECTION OF FLOW OF MINERALIZING SOLUTIONS.

W. H. NEWHOUSE.

ABSTRACT.

In a moving solution a crystal grows most rapidly on the side that faces the direction of flow. This is because nutrient material is carried to it on this side by bodily movement of solution, and also by diffusion, while on the lee side of the crystal the nutrient material is carried in large part only by diffusion. Thus, the direction of solution movement can often be determined by examination of the growth zones in minerals. This is usually done by sectioning the minerals. Lineages where present may also be used to determine the preferred growth direction. Crystal distortion may also be used. Overgrowths of crusts or scattered small crystals resting on an earlier crystal or other object also afford good evidence. Preferred corrosion or solution of a mineral or mineral aggregate is analogous. The vectorial properties of crystals interfere to some extent.

These features have been studied on crystals formed in the laboratory and on many minerals and ores. The experimental work and several examples of ores and minerals are briefly described.

INTRODUCTION.

A KNOWLEDGE of the direction of movement of the solution that formed a particular ore deposit should often be of value in exploration. If an ore body is associated with several structural features, there is frequently disagreement among geologists as to the relative importance of each of these features in guiding the solutions and in localizing the ore. In some fault veins the position and attitude of the ore shoots, when considered with the strike and dip of various portions of the fault and the direction of fault displacement, strongly suggest that the solution channelway may locally have a strong horizontal component. In such examples it might be of value to guide lateral exploration along a proven solution channelway. The feeding fissures or fractures that led solutions into some ore bodies cannot always be identified with certainty.

If the direction of movement of the solutions that formed the ore can be determined, and if this is done with full consideration of the structural features, or rather guided by them, the resulting information may aid in giving conclusive answers to these problems. On the following pages a method is described by which this direction may often be determined. This method in principle is independent of structural features or theories, or temperature zoning effects, but in practical use the method should be correlated with the structural features as closely as possible. The methods described are in part based on experimental work in which a number of compounds were crystallized from flowing solutions. In other experiments crystals and crystal aggregates were corroded or dissolved in a current or flowing stream. Examination of many ore and mineral specimens supplement the information obtained by experimental work.

THEORY.

An imaginary plane normal to the line of flow of a moving solution is not a plane of symmetry. Consequently, the field of environment of a fixed crystal or group of crystals growing in a moving solution is not symmetrical with respect to the stoss [1] and lee sides of the crystals. It would therefore be expected that any chemical activity of the solution would be asymmetric.

EXPERIMENTAL WORK.

Apparatus.—A simple apparatus was made of sheet celluloid, in which crystals could be grown under the microscope in a moving solution. It consists of a rectangular tube (1×1.5 cm.) roughened on the inside and 35 cm. long. Attached to one end is a piece of rubber tubing nearly closed by a pinch cock that governs the rate of solution flow; a large funnel constituting the solution reservoir is attached to the other end. This funnel is held by a ring stand a foot or so above the horizontally placed rectangular tube. The rectangular tube passes through the side walls of a small cylindrical dish (10 cm. in diameter and 6 cm. high). This

[1] The stoss side faces the direction from which the solution comes.

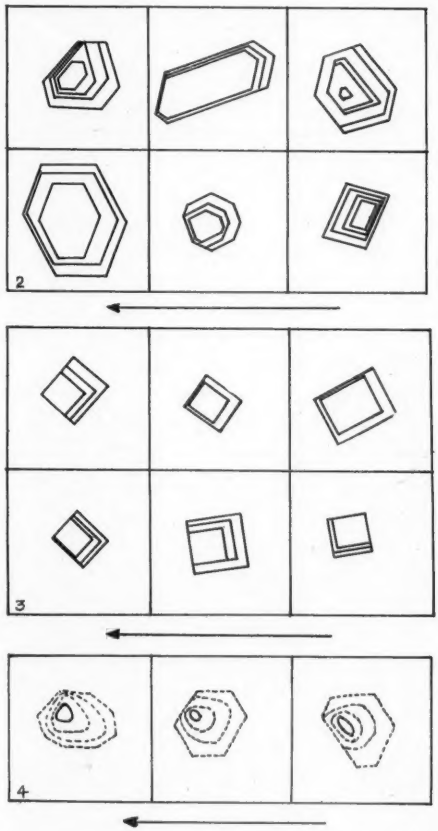
dish rests on the microscope stage and is partly filled with water a little cooler than the solution. Crystal growth was observed with a UM4 Leitz objective which gives fairly high magnification with a long working distance. Good results were obtained by using this objective with an immersion water cap, the water in the dish being adjusted to the required level for immersion.

Experimental Procedure.—A warm saturated solution of the salt to be crystallized was placed in the funnel and the pinch cock

FIG. 1. Dendritic crystals of ammonium chloride grown in a solution moving in the direction of arrow. Growth began at the point where the four main arms meet and was most rapid on the stoss side, × 6.

adjusted to give a flow of solution of about one foot in three to four minutes. Strong transmitted light projected the image of the growing crystals on the glass of a photo-micrograph camera. Successive tracings of the images of the growing crystals were made on thin tracing paper. Large numbers of these were made, a few typical examples being shown in Figs. 1–3.

Crystal Formation.—Ammonium chloride, potassium chloride and potassium alum were the salts used for study since these form isometric crystals of different habits.



FIGS. 2, 3. Growth zones formed in a solution moving in the arrow direction. The section is parallel to the wall of the conduit. In closely spaced crystals eddy currents produce some reversals as shown in lower right.

2. Potassium alum crystals showing combinations of cube octahedron, $\times 75$.

3. Potassium chloride crystals, which are cubes, $\times 75$.

FIG. 4. Solution stages of crystals of potassium alum. Broken line outlines crystals before solution began, and solid line represents the near final stage of solution, $\times 75$.

These salts all formed crystals in which in general the growth is more rapid on the stoss side (Figs. 1–3). The reason for this is that ions are carried to the crystal by both diffusion and solution movement on the stoss side, while only diffusion in a more or less static, partly depleted and relatively little moving mass of solution adds ions on the lee side of the crystal. Dust-like particles of inert material were added to the solution in certain experiments in order to observe the details of stream flow around the corners of the crystals, and the reversed eddy currents set up by larger crystals, or crystal groups.

A blocky crystal with poor streamlining often has on its lee side a mass of slowly swirling solution, which is probably in part depleted or relatively less saturated than the fresh solution approaching the stoss side of the crystal. If the slant of a face is such as to permit a large amount of current to sweep by at nearly maximum speed, this face grows very rapidly in comparison with the other faces of that form. Two closely adjacent crystals may draw nutrient material from the same small zone or limited field of diffusion and one may rob the other or inhibit deposition on the nearest faces of its neighbor.

The exact direction of maximum crystal growth is thus dependent on a number of factors other than the main direction of solution movement. These include position of the crystal with respect to the solution channelway wall, slant of the crystal faces toward the line of solution movement, streamlining of crystal and preferred growth on certain crystal forms or directions of the mineral species, vectorial properties, and robbing or interference by adjacent crystals.

Due to these conflicting factors and also to the local divergent strands of flow through a closely spaced group of crystals, it is usually not possible to determine the direction of solution movement within less than 15–20°.

Crystal elongation produced by moving solutions can be used to determine the line of movement only if a considerable number of elongations are averaged. Non-isometric crystals would often prove difficult to interpret. The direction of greatest crystal

growth is much more precise than crystal elongation as a means of determining the path of solution movement. In addition to showing the pathway or line followed by the solution, crystal growth addition also shows the direction of solution movement. In minerals and ores several features may be used to measure or align the direction of greatest crystal growth, as will be shown later. After determining successive stages of growth in either artificial or natural crystals a convenient element to plot is obtained by drawing a line from the original nucleus of the crystal to the center of gravity of the full-grown crystal.

Crystal Overgrowths.—Any body that acts as a baffle to a portion of a moving precipitating solution receives the maximum precipitation on the stoss side. Small blocks of glass placed in the experimental apparatus were coated with crystals on the stoss side, while few or none were deposited on the lee side. This was true not only in aqueous solutions but was also well displayed in a current of sublimed ammonium chloride.

Corrosion, or Solution.—Single crystals and crystal aggregates of various substances were placed in the apparatus and dissolved but when acids were used as solvents the glass tubing was employed. The removal of material by solution in a moving stream was found to take place more rapidly on the stoss side (Fig. 4) partly because of the relatively quiescent solution in the lee of the body. Partial saturation of the solvent lessens the rate of corrosion. In contrast, on the stoss side a continuous flow of fresh unsaturated solution is available to remove material.

SUMMARY OF THE STOSS AND LEE FEATURES OF CRYSTALS FORMED BY A MOVING SOLUTION.

In addition to the experimental work in which crystals were grown in a moving solution, many mineral specimens, mineral aggregates and ores were studied. In the study of natural specimens particular attention was given to see whether all of the asymmetric features on a specimen would indicate the same direction of solution movement. They were found to give generally

concordant results on the specimens examined, although this would certainly not always be expected.

The later descriptions of individual examples of minerals and ores illustrate certain of the principles and also give some idea of the problems encountered and of the methods used in examination.

The results may be summarized as follows:

If the crystal is stationary and the solution is moving, the direction of solution movement is indicated by:

1. Preferred Growth on the Stoss Side of a Crystal.—A crystal attached to a wall and growing outward in open space may display the greatest single component of shift of center of gravity during growth, in a direction outward from the wall. In a plane parallel to the wall, the greatest shift of center of gravity is toward the stoss side.

Preferred growth on one side of a crystal may be determined in several ways.

(*a*) Growth zones may be visible in a transparent or translucent crystal and may be examined and measured by sectioning the mineral. Such zones are often visible, for example, in quartz, calcite, garnet, fluorite, sphalerite and cassiterite.

(*b*) Growth zones in opaque minerals may often be made visible by etching polished sections.[2] The growth zones are outlined by minor, or even major, impurities or variation in the composition of the crystal during its growth. Since the suite of minor elements may vary in a mineral species from different places[3] the necessary etching procedure may have to be varied.

The writer has been unable to etch the highest temperature examples of a number of mineral species, so as to reveal growth zones. It may be that near the highest temperature range of formation for a given mineral species, diffusion in the solid tends to

[2] Van der Veen, R. W.: Mineragraphy and ore deposition, 1925. Schneiderhohn, H. and Ramdohr, P.: Lehrbuch der Erzmikroskopie, 1931.

[3] Claussen, G. E.: Spectroscopic analysis of certain galenas, sphalerites and pyrites. Amer. Min. 19: 221–224, 1934. Stoiber, R. E.: Minor elements in sphalerite. Econ. Geol., 35: 501–519, 1940.

homogenize the crystal.[4] It seems more probable in view of Tuttle's results that the more homogeneous crystals were originally deposited without notable growth banding.

(*c*) Lineages are longest toward the stoss side. According to Buerger the lineages descend branchwise from the original nucleus of a crystal.[5] Lineages are particularly well displayed on the cleaved surfaces of many galena crystals and the results of this study corroborate Buerger's conclusion. The lineages of galena may be seen on cleaved crystals and are also revealed in the grinding stage of making a polished section, where the numerous cleavage pits will be seen to slightly diverge from one lineage or branch to the next one.

(*d*) Crystal growth distortion. Since the nutrient material is added more rapidly to the stoss side of a crystal the faces grow more rapidly on that side. The deposition of new layers of material on a face that forms a solid angle of more than 90° with the adjoining faces results in a lessening in size of that crystal face, if less material is deposited on the adjoining faces (Fig. 2). The terminal rhombohedrons on quartz crystals often show this feature (Fig. 7). Since these two rhombohedrons are usually not equally well developed, each group of the three *r* faces and each group of the three *z* faces must be considered separately. Hence the size of an *r* face can only be compared with other *r* faces, and similarly a *z* face with other *z* faces. On these crystals the smaller *r* faces and the smaller *z* faces have received the most abundant additions of material, and if the crystal is in a free, unimpeded current they are on the stoss side.

The more rapid addition of material on the one side tends to produce an elongation of the crystal. This is most easily detected and measured on cubes, which form is frequently taken by pyrite, galena and fluorite. The diameter of the prism of quartz

[4] Attempts have been made by O. F. Tuttle to homogenize galena and stibnite that display growth banding when etched. These were held at 300° C. for 30 days without appreciable loss of sharpness of the growth zoning. The galena was also held at 500° C. for 21 days without results.

[5] Buerger, M. J.: The lineage structure of crystals. Zeit. für Krist. 89: 195–220, 1934.

is another example. Since the nuclear crystals at the beginning of growth present a great variety of angles to baffle or to streamline the current, the stoss "side" may in actual effect comprise as much as 180° of the circumference of many crystals. For this reason the crystal elongation of an individual crystal does not usually exactly parallel the line of solution flow, and numerous examples must be considered if this factor is to be given any weight in reaching a decision. Furthermore, this feature gives only the line of flow and does not indicate which of the two possible directions of solution movement along this line is the true one.

2. *Overgrowth.*—An overgrowth or incrustation (a crust of mineral, or scattered crystals) is formed in largest amount or entirely on the stoss side of a crystal or other object such as a rock fragment or projection. Although the term overgrowth is usually applied only to deposition of a new mineral or minerals on an earlier crystal, extension of the idea to growths on other objects is obvious. Overgrowths on older crystals must be interpreted with a full realization that preference is often shown by the later mineral to deposit on certain of the forms present on the earlier crystal. Frondel [6] has described a number of examples of such selective action. In actual practice there is usually little difficulty in deciding the relative value of the influence of selective face or crystal form incrustation and current incrustation. Work on ore deposits during the last three decades has tended to emphasize the fact that ore-forming solutions change in composition so that different minerals or different proportions of minerals are deposited at different stages in the growth of an ore body. The incrustations just described result from such changes, and in the examples studied by the writer the solutions that formed the incrusted crystal and the later incrustation were clearly moving in the same general direction. Evidently for these examples the early channelway had not become choked, with a resulting change in solution pathway.

[6] Frondel, C.: Selective incrustation of crystal forms. Amer. Min. 19: 316–329, 1934.

3. Preferred Corrosion or Solution of a Crystal or Crystal Aggregate.—The influence of a current is to give increased corrosion or solution on the stoss side. After deposition of a mineral or group of minerals the continually changing solutions may deposit new minerals, or they may change so as to corrode, etch, or dissolve the earlier minerals. For example, if any of the rhombohedral faces on a quartz crystal were etched by the mineralizing solutions, the etching will in general be greater on the smaller of the *r* faces and the smaller of the *z* faces. This has been observed on quartz from a number of localities and is in harmony with the experimental results. As with overgrowths, a modifying feature is the influence of the vectorial properties of crystals, since it is well known that the faces of certain forms on a crystal may etch before those of other forms on the same crystal.[7] The problem of interpretation is thus analogous to that of crystal overgrowths.

The possibility of etching or corrosion by later supergene solutions is, of course, to be considered. Another feature that may produce confusing relations is gravitational settling of large colloidal particles or small crystals in a near static solution.[8] The rate of solution flow may perhaps vary greatly in the formation of different types of ore deposits. In some types it may be very slow and gravitational overgrowths may be found to characterize such mineralizations. Certainly, within a given solution channelway the rate of solution flow must be more rapid in the more constricted parts of the channelway than in the wider and more open parts. Upward moving solutions[9] would present a larger component in opposition to such gravitative settling than would those moving laterally. In some cases the last stage of mineralization might leave any remaining openings filled by a nearly static solution from which a late gravitational overgrowth would settle.

[7] Honess, A. P.: The nature, origin and interpretation of the etch figures on crystals, 1927, p. 6. Frondel, C.: Vectorial chemical alteration of crystals. Amer. Min. 20: 852–862, 1935.

[8] Frondel, C.: Oral communication.

[9] See principles of elutriation. Richards and Locke: Textbook of Ore Dressing. McGraw-Hill Co. 1940, pp. 470–471.

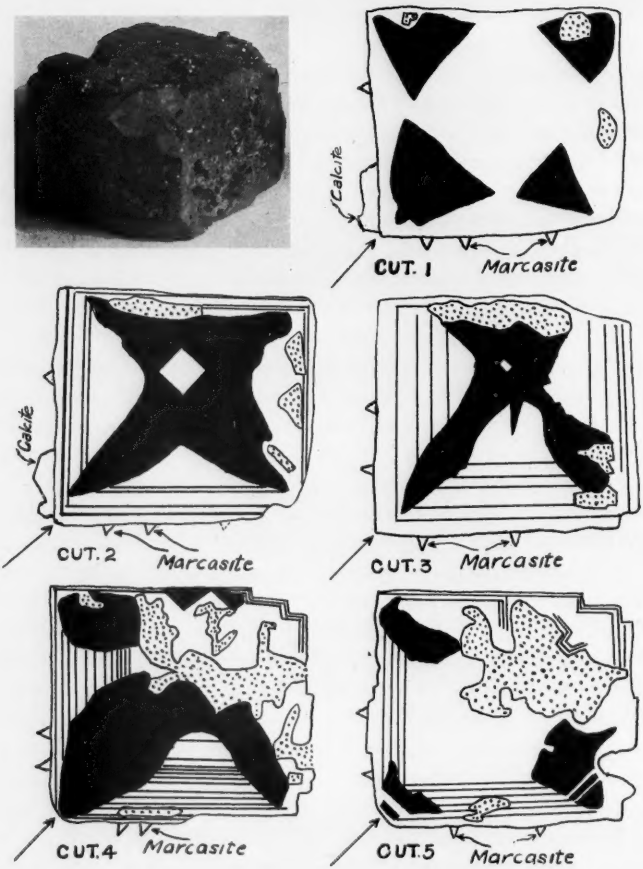


FIG. 5. Galena cube with overgrowth, Tri-State district, with sections showing its internal structure. The marcasite overgrowth is confined to three cube faces, and calcite one cube corner. The "cuts" display etching features on polished sections, × 2. Cut 1 is parallel to and near the top cube face, and may be oriented by the calcite. The other cuts are parallel and equispaced. Black lines and black areas represent galena that etches one color; black areas are developed along octahedral directions and con-

Bastin [10] describes late overgrowths of small calcite, fluorite, barite, chalcopyrite, and pyrite crystals resting on the upper faces of fluorite crystals in vugs in the southern Illinois fluorite veins, which he considers as having settled under gravitative force from the solutions that filled the vugs.

SOME EXAMPLES OF STOSS AND LEE FEATURES OF MINERALS FORMED BY MOVING SOLUTIONS IN OPEN SPACE.

Numerous specimens from many localities have been studied and the few to be described have been selected to bring out some of the methods of examination and practical problems encountered in applying the general principles developed.

First, study was made to see whether the various asymmetric features would corroborate each other in indicating the direction in which the mineralizing solutions were moving during the growth of the minerals. The several features on a specimen were found to give generally concordant results. This statement is to some extent qualified by the fact that a high degree of accuracy is not aways possible, and therefore some slight shifts in the direction of solution flow may not have been recognized. Although local changes in the direction of solution movement would be expected during the filling of veins, none have been recognized on the examples studied. It seems reasonable to expect that such local changes will be found when complete studies of veins are made.

Galena with Current Overgrowths of Marcasite. Joplin, Missouri.—About one dozen cubes of galena with marcasite over-

[10] Bastin, E. S.: The fluorspar deposits of Hardin and Pope Counties, Illinois. Ill. Geol. Surv. Bull. 58: 39–41, 1931.

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tain about ten times as much silver as the rest of the crystal. Dotted areas are negative cavities. The arrow points to the greatest component of current direction, which is indicated by: (*a*) compositional or growth banding showing heaviest growth on the stoss side; (*b*) overgrowth of marcasite and calcite; (*c*) longest lineages toward the stoss side (not shown here); (*d*) largest growth of one kind of galena toward the stoss side; (*e*) the position of the negative cavities is also probably significant.

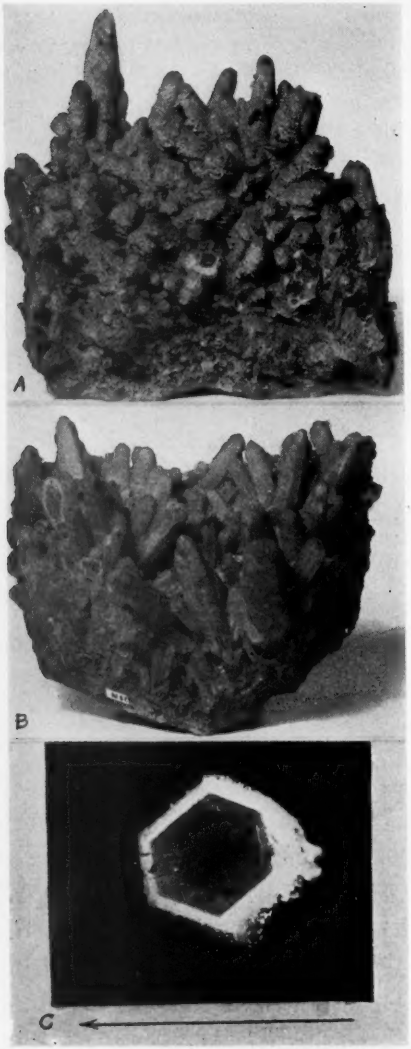

FIG. 6.

growths were studied. The method of study was to grind off a layer two or three millimeters thick parallel to a selected cube face, then polish and etch with dilute nitric acid. Successively deeper cuts were made and studied.

The results obtained give a three dimensional picture and show that each galena crystal has a strong growth asymmetry. The cube regarded as one unit is far from isotropic in composition and in gross physical make-up. Compositional growth banding, lineages, the relationships of the two galenas of different composition within the one crystal, and the marcasite overgrowths all give corroborative asymmetry indicating the direction of movement of the solution that formed the minerals. These features are shown for one crystal in Fig. 5 and will be briefly described.

The compositional growth banding is generally developed best near the outer parts of the crystals. In etching a crystal section near to and parallel to the " top " face it was found that four triangular shaped areas near the cube corners etched brown[11] with sharp contacts to the adjoining galena. With progressively deeper cuts these triangular areas retreat toward the original crystal nucleus, i.e., toward the " root " or face of attachment to the wall of the conduit. Cleavage pits continue without interruption across the boundaries of these triangular areas into the adjoining areas, in contrast to the break in cleavage direction at lineage boundaries. It was also noticed that a number of the small compositional

[11] Brown when viewed under binoculars in light near limit of angle of reflection. Relatively greyish when viewed perpendicular to surface.

FIG. 6. Quartz crystals with current overgrowth, Las Chispas, Sonora, Mexico.

A. View of stoss side quartz crystals covered by overgrowth, which consists of quartz, a clay-like mineral, and stephanite.

B. Reverse side of *A*, showing clean quartz crystals.

C. A crystal of this group cut normal to C axis, × 5, showing transparent (dark) quartz in the center, surrounded by translucent (white) quartz. Direction of solution movement (see arrow) is shown by: (*a*) heaviest growth band of white quartz on one side; (*b*) overgrowth on same side (the rough irregular part of the crystal outline); (*c*) the rhombohedral faces of the quartz crystals of the group are smaller on the same side (not shown here).

growth bands, etched to approximately the same shade as these triangular areas, which suggested a similar composition. These facts and others suggested that galena of two slightly different compositions are present.

Spectrographic analyses of these differently-etching kinds of galena were made on a 21-foot grating spectrograph and it was found that different proportions of minor elements are present in the two kinds. Thus, etching brought out compositional differences in single galena crystals that are probably analogous to slight variations in calcites or sphalerites of different appearance.

In summary, these crystals of galena as shown by growth zoning, by lineages, and also by the relations of the two kinds of galena, grew most rapidly in the direction of the front or stoss face; this notwithstanding the fact that after the crystals attained some size, the compositional growth banding is heaviest on the "top" face, *i.e.*, growth was most rapid normal to the side of the solution conduit.

The marcasite overgrowth was clearly deposited on these galena crystals by solution moving in the same general direction as that which deposited the galena.

Quartz with Current Overgrowth of Unknown Mineral. Las Chispas, Sonora, Mexico.—Specimens of silver ore from Las Chispas display quartz crystals, partly amethystine, that evidently grew outward from the wall into an open cavity in the vein (Fig. 6). These quartz crystals have a heavy current overgrowth of fine-grained quartz, a clay-like mineral, and scattered stephanite crystals.

Sections of the quartz crystals cut normal to the *c* axis show that they grew most rapidly on the side covered by the overgrowth (Fig. 6). The solution that formed the large quartz crystals continued coming from the same direction to form the overgrowth.

Quartz Crystals. Arkansas.—The line of movement of the solutions that formed the group of crystals shown in Fig. 7 is indicated by rough parallelism of the greater diameter of the prism (as measured parallel to the *a* axes of a second order prism). About 17 crystals of the group shown in Fig. 7 display their greater diameters lying within an angle of about 40°. Four

or five crystals have greater diameters trending outside this angular limit. The direction of solution movement is further indicated by, (*a*) the smaller rhombohedral faces on one side, (*b*) preferred natural etching of both rhombohedral faces and

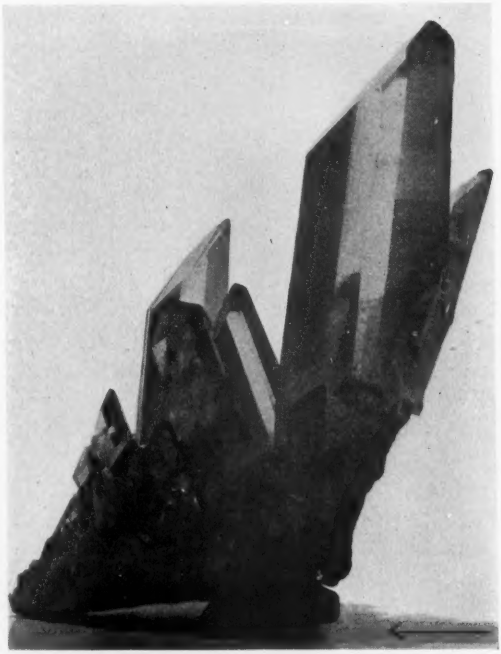

FIG. 7. Quartz crystals, Arkansas. Direction of solution movement indicated by arrow.

prism faces on the same side, (*c*) deposition of an undetermined mineral to form an overgrowth in small patches on the same side near the base or point of attachment of the crystals.

STOSS AND LEE FEATURES OF MINERALS FORMED BY REPLACEMENT.

Where minerals have been deposited as closely spaced nuclei to grow and form grains or crystals that touch and mutually inter-

fere with each other's growth, the interpretation of the asymmetric features is difficult and can only be done by examining large numbers of grains or crystals. The examination of such material is made by sectioning, using either thin sections or etched polished sections according to the opacity of the minerals, in order to display the growth banding. Parallel sections would need to be cut in order to reveal the growth banding in three dimensions.

In addition to control of mineral deposition by faults, fissures, shear zones, bedding or other major structural features, the local or smaller features are known to have importance at times. Such local or small features include joints or small fractures, varying permeability of different portions of bedding laminae, crystal and grain boundaries, lineation, and so forth. Preliminary study of ore specimens from replacement ore bodies leads the writer to believe that such local structural features of the host rock must be carefully considered since only the local direction of solution movement is determined from any one specimen.

Growth of new minerals in host rock may possibly at times take place by diffusion through a more or less static body of solution that permeates the rock, and which acts merely as a medium through which the ions diffuse from a channelway of high concentration to the mineral being formed. Preferred growth on one side of a crystal formed by replacement might take place on the side toward the channelway. No experimental work has been done on this problem. Theoretical considerations suggest that if a crystal grew in the region of a high concentration gradient, it would probably show preferred growth toward the side of high concentration, but in a low gradient little preferred growth would be expected.

Growth asymmetry has been observed in sections of pyrite, sphalerite, and galena that came from deposits considered to have been formed by replacement. A photograph (Fig. 8) is given of a section that illustrates the effect as observed in two dimensions only. No complete study of a replacement ore body by these methods has been made.

Special Problems.—The so-called clay minerals are sometimes found as overgrowths on earlier crystals in vugs. Study of such material by these methods would form a very interesting contribution on the genesis of the clay minerals in hydrothermal ore deposits.[12]

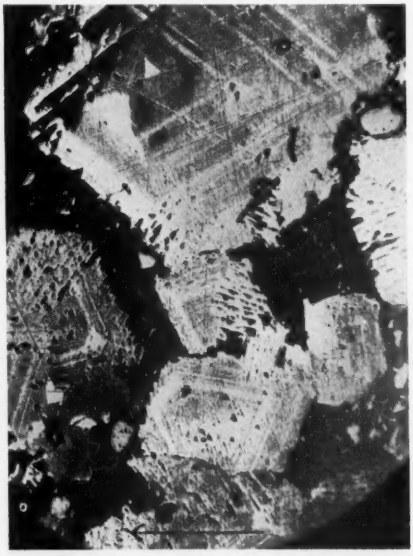

FIG. 8. Growth or compositional zoning in galena from Southeastern Missouri lead deposits. Polished section parallel to bedding, etched by dilute nitric acid. Possible solution movement shown by arrow but this two-dimensional analysis is inconclusive.

Similarly the hypogene or supergene origin of certain copper and silver ores might be conclusively settled. Some use of the methods in the problems of metamorphic geology is to be expected.

MASS. INSTITUTE OF TECHNOLOGY,
CAMBRIDGE, MASS.
May 5, 1941.

[12] Ross, C. S. and Kerr, P. F.: The kaolin minerals. U. S. Geol. Surv. Prof. Pap. 165: 174–176, 1930. Lindgren, W.: Mineral Deposits, 1933, pp. 353–354.

ORIGIN AND MINING OF BAUXITE IN NETHERLANDS–INDIA.

R. W. VAN BEMMELEN.[1]

ABSTRACT.

Bauxite production on Bintan Island (near Singapore) began in 1935 and at present amounts to about 5 to 6 per cent of the world production. The bauxite is of the aluminous laterite type.

The parent rock of this aluminous laterite is an aphanitic hornfels, with nuclei of feldspar and quartz, and a silica content of about 65 per cent. The process of lateritization can be studied in a section exposed by a shaft sunk below the bauxite layer. This shaft reached the unweathered parent rock at a depth of 52 meters.

Conclusions can be drawn regarding the conditions favorable for bauxite formation in this region and directions are given for further exploration in the Netherlands Indies.

INTRODUCTION.

THE bauxite production of the Netherlands Indies started in 1935 with nearly 10,000 metric tons and rapidly increased to more than two hundred thousand tons in 1938 (about 5 to 6 per cent of the world production).

	1935	1936	1937	1938	1939
Netherlands Indies	9,923	133,731	198,970	242,634	230,668
Johore (Unfed. Malay States)	—	37	13,627	55,080	93,740
Indo-China	—	30	7,000	160	?
British India	7,758	3,702	15,393	14,768	?
World production	1,767,000	2,829,000	3,746,000	3,849,000	±4,400,000

Bauxite production of the Japanese mandated islands in the Pacific is not published but is relatively small. The ore reserves of these islands probably amount to a few million tons.

In a few years the Netherlands Indies became the most important bauxite producer of the Far East, and the aluminum in-

[1] Geologist, Geological Survey, Netherlands Indies.

dustry of Japan depends largely on this source of ore, since Manchurian shales and Korean alunite have given unsatisfactory results as raw materials.

The know bauxite reserves of the Netherlands Indies (10–20 million tons) occur in the Riau-Archipelago, especially on the island of Bintan and the surrounding islets. Bintan lies just opposite Singapore (Fig. 1).

The deposits are worked by the Nederlandsch Indische Bauxiet Exploitatie Maatschappij, which has mines on both sides of the Strait of Kidjang at the southeastern side of the island (Fig. 1).

The ores are formed by lateritic layers of hard aluminous concretions in a matrix of soft clay. The concretions make up 60 to 80 per cent of the ore, and usually range from nut to fist size. In places they are cemented together, forming large blocks or lenses. The concretions mostly have rather sharp edges. They consist of gibbsite ($Al_2O_3.3H_2O$), goethite ($Fe_2O_3.H_2O$) and small amounts of other impurities such as silica. These lateritic layers attain a thickness of 2 to 10 meters (average 4 meters) and are mined by power shovels.

The ores mined on the islets on the eastern side of Kidjang Strait are transported across the strait by a cable-way.

At the deposit of Sungei Kolak, lying on the western shore of the strait, the ore is washed in order to remove the associated clay. This treatment diminishes its silica content. The ore is sometimes calcined at 110° to reduce the moisture content and then goes to the bunkers, from which it can be loaded directly into ocean freighters which come alongside the landing-stage.

The Bintan bauxite, shipped in 1936, had the following average composition: 53% Al_2O_3; 2.5% SiO_2; 13.5% Fe_2O_3 and 1.2% TiO_2. At present the silica content of the ores shipped is somewhat higher. The ores are the lateritic type, referred to as aluminous laterites. They have a composition different from the classic Mediterranean bauxites (Terra Rossa type), which consist chiefly of aluminum-monohydrate ($Al_2O_3.H_2O$). For convenience, however, aluminous laterites that are commercial aluminum ores are usually called bauxite and that term will be used.

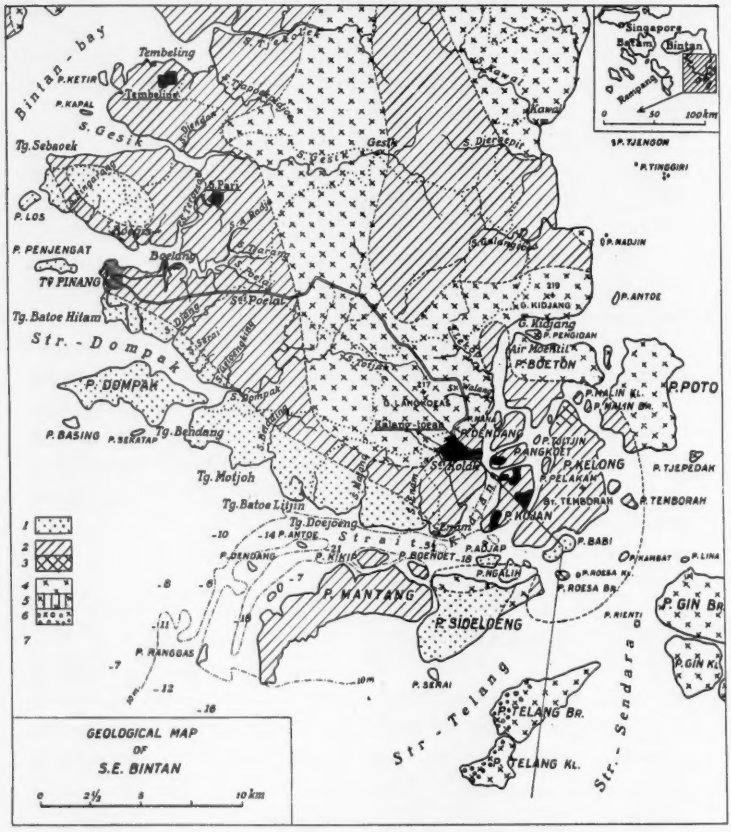

FIG. 1. Geological map of Southeast Bintan, with inset situation map of Bintan Island (after Bothé, Mett, Meyer and own observations).

Legend: 1. "Plateau-sandstone" formation (Tertiary).
2. Shales and pseudo-rhyolitic (or pseudo-trachytic) hornfels (Triassic).
3. Contact metamorphic diabases (pseudo-lamprophyric hornfels (Triassic)
4. Post Triassic granites and associated rocks.
5. Post Triassic (quartz) mangerites.
6. Post Triassic granulites (= contact metamorphic triassic quartzites).
7. Bauxite concessions.

In order to determine if possible the genesis of the Bintan bauxites the author made a study of the geology of this region and the processes of lateritic weathering.

GEOLOGY OF BINTAN AND THE SURROUNDING ISLETS.

Three groups of rocks can be recognized:

1. A group of shales, arenaceous shales, and quartzites, comparable with the Triassic formation of Malaya and Singapore, and of metamorphosed volcanic rocks comparable with the Pahang Volcanic series of Malaya.[2]

2. Granitic and associated rocks (granites, aplite-granites, granite-porphyries, rhyolites), which have intruded those of group 1. These intrusives are surrounded by metamorphic aureoles and represent the same igneous activity that gave use to the tin ores of the Malayan tin belt. They are, most probably, of Jurassic age and, as will be pointed out subsequently, may not be true intrusions.

3. Arkosic sandstones and clay-shales with coal layers that were deposited much later, after a long period of peneplanation. They are probably of Tertiary age and can be compared with the "Plateau-sandstone" formation of Western Borneo.[3]

A petrographic and chemical study of the processes of alteration in the rocks of the contact metamorphic zone, as well as field observations of their transition into the granitic intrusions, led the author to believe that the granites themselves are probably of metasomatic origin instead of intrusions of silicate melts.

The "granitization" was effected by the introduction of silica, alumina, and alkalies under hydrothermal conditions. As a result, aluminous shales were silicified and quartzites impregnated with alkali feldspars. The final product is an aplitic granite with 76 to 77 per cent SiO_2. Thus, sedimentary and volcanic rocks developed in igneous texture.[4]

[2] Scrivenor, J. B.: The Geology of Malaya. Macmillan, London, 1931.

[3] Van Bemmelen, R. W.: The geology of the western and southern part of the Department West-Borneo. Jaarb. Mijnw. in Nederl. Indië, Batavia, 1939, p. 319.

[4] On this subject of granitization see also the following papers of the present author: On the origin of the Pacific magma types in the Volcanic inner arc of the

The first stage of the granitization of the clayey Triassic rocks is the formation of black, aphanitic, hornfels. Porphyroblasts of feldspar and quartz, also of biotite, amphibole, and epidote, may give these hornfels rocks a pseudo-rhyolitic appearance, and if quartz fails, they may resemble trachytic rocks. The groundmass is felsitic, trachytic, or granoblastic (microgranitic).

These black, aphanitic, contact metamorphic, hornfels rocks are the parent rocks of the bauxite deposits of Bintan.

OCCURRENCES OF ALUMINOUS LATERITE AND BAUXITE ON BINTAN.

Bauxite concretions occur in the top part of the weathered granitic rocks as well as above weathered clay shales. The bauxite concretions above the granitic rocks nearly always contain too much quartz to be of any commercial value. The cover of bauxite concretions above the contact metamorphic, hornfelsic shales, however, often has a thickness of several meters and locally its quartz content is low enough for the concretions to be mined as aluminum ore. In some fields, especially those around Kidjang Strait (southeast of Bintan) and in northwest Bintan, the cover with bauxite concretions is several meters thick (maximum 10 meters on Kojan and the interstitial clay makes up only 20 to 40 per cent of the entire mass. The concretions rarely exceed a few centimeters in diameter. At the top of the concretionary layer some few ferruginous concretions occur amidst the aluminous ones, but in places at the base of the layer, large limonitic lenses may be observed. Instead of a limonitic cover ("cuirasse de fer") on the top of the bauxite, as in British India, these bauxite layers of Bintan may have a limonitic layer at their base.

Sunda Mountain system. De Ingenieur in Nederl. Indië, Sect. IV, Geologie, 5: 1–15, 1938; The volcano-tectonic origin of Lake Toba (North Sumatra). Op. cit., 6: 126–140, 1939; On the origin of some granite of Singapore. Op. cit., 7: 25–35, 1940; The agmatitic granite of Tandj. Binga (Billiton). Op. cit., 7: 63–66, 1940; Bauxiet in Nederlandsch-Indië. Verslagen en Mededeelingen Ind. Delfstoffen, No. 23, Dienst Mijnbouw in Nederl. Indië, Batavia, 1941; Granitic intrusions in the Zuider Mountains of West Java. De Ingenieur in Nederl.-Indië, Sect. IV, Geologie, 8, No. 2, 1941. Analogous phenomena of granitization have been described in the United States by Goodspeed, G. E.: Pre-Tertiary metasomatic processes in the southeastern portion of the Wallowa Mountains of Oregon. Proc. Sixth Pacific Sci. Congress, p. 399–422, 1939.

The aluminous concretions consist of gibbsite in small flakes and crystals 0.01–0.04 mm. in diameter, and goethite (microclitic). Sometimes the outlines of former phenocrysts of the parent rock (probably feldspars), which were replaced by gibbsite, can be recognized by the arrangement of goethite microliths along their borders. These outlines of the crystals were preserved in the lateritic clay, and later on, were preserved again by the replacement of the soft weathering products (kaolinite) by hard, crystalline gibbsite. This demonstrates that no mechanical erosion acted on the lateritic clay, and that only chemical changes such as solution and supergene replacement occurred in these places.

Shallow drillings with the Bangka drill in the swamps and straits between the islets of Kojan proved that the bauxite layer does not extend below sea level. These straits are former valleys on the peneplain of the Sunda continent where the bauxite cover had, for the greater part, been eroded. These valleys then became submerged in late Quaternary time during the general transgression of the sea over the Sunda continent. The tidal streams in these straits first cleaned out these valleys, some of which were filled later with estuarine clays and became brackish swamps.

In order to study the complete section of lateritic weathering connecting the bauxite ore with the parent rock, the Nederlandsch-Indische Bauxiet Exploitatie Maatschappij sank a shaft under the bauxite layer of the Kalangtoea field on the site of Soengei Kolak. This shaft, $1\frac{1}{2} \times 3$ meters in horizontal section, reached a depth of 54 meters. The top of the shaft is 20 meters above sea level and is situated a few hundred meters from Kidjang Strait.

The first 7 meters of the shaft went through bauxite cover, Zone I (Fig. 3), followed by 45 meters of a tough, spotted clay. This clay seemed to be structureless in the upper part, Zone II (7–26 meters), whereas in the lower part (Zone III, 26–48 meters) streaks of intensely weathered, siliceous rocks could be observed. At 48 to 52 meters the clay contained blocks of unweathered parent rock. At 52 meters depth the unweathered parent rock was reached (Zone IV). The shaft was sunk for

another two meters in this rock and then stopped at a depth of 54 meters.

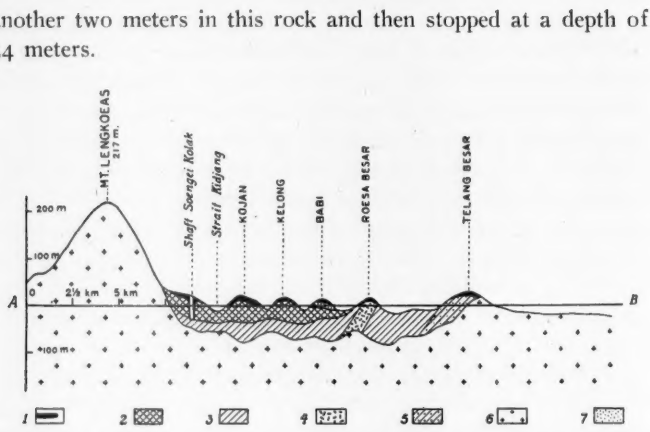

FIG. 2. Section *A–B* across Southeast Bintan and neighboring islets.

Legend: 1. Aluminous, lateritic cover (on the "Plateau-sandstone" formation it has an alluvial or lateritic character).
2. Lateritic clay.
3. Pseudo-rhyolitic or pseudo-trachytic hornfels (with porphyroblasts of feldspar and quartz).
4. Pseudo-spessartitic hornfels (contact metamorphic diabases).
5. Granulites (contact metamorphic Triassic sandstones).
6. Granites, granite prophyries, rhyolites.
7. "Plateau-sandstone" formation.

Origin of the Bintan Bauxite (Fig. 3).—The study of the lateritic soil profile, exposed in this shaft, gave the following information regarding the genesis of the lateritic bauxite layers in this wet, tropical climate.[5]

The parent rock is a brecciated, hard, black, aphanitic hornfels of the pseudo-rhyolitic type. In the first stage of solution the alkalies and part of the silica were extracted, causing the disintegration of the hard rock into a tough clay. The reaction of the water collecting at the bottom of the shaft is alkaline (pH =

[5] For further details see the author's memoir: Bauxiet in Nederlandsch-Indië. Verslagen en Meded. betr. Ind. Delfstoffen, No. 23, Dienst van den Mijnbouw in Nederl. Indië. Pp. 110; Figs. 8; Photos, 37, Batavia, 1941 (in press).

8.03). In this first stage of leaching about one-third of the original rock volume was extracted. This process of leaching of the alkalies is far ahead of the removal of other constituents, for in the next 20 meters the changes in the chemical composition of the clay are inconsiderable. At 32 meters a slight rise of the silica-content may indicate some precipitation of silica, which was leached from the upper part of the weathering profile. This might be compared with the siliceous " lithomarge " of the lateritic profiles in British India.

Above this point the silica content of the clay becomes gradually lower the nearer the bauxite cover is approached, but the content of alumina, ferric oxide and titanium oxide increases. This probably results from leaching of the rest of the free quartz and of some kaolinite.

At the bottom of the bauxite layer the clay decreased to a quarter or a third of the original volume of the parent rock. Finally, the main leaching occurred at the border of the bauxite layer and the spotted clay. Here the flow of ground water, which has a pH value of about 6 or slightly acid, took away nearly all the kaolinite in sol-form, while the aluminum- and iron-hydroxides remained behind. When the rain water, penetrating into the upper layer, contains humic acids and CO_2, locally the pH may be temporarily lower than 5 and the iron- and aluminum-hydroxides will be dissolved. Rapid destruction of the humic acid by the strong bacterial activity in the tropical climate, however, will reprecipitate these components. Thus, lateritic concretions will be formed in the top layer directly above the ground water level. The results of this process of alternating solution and precipitation of the aluminum- and iron-hydroxides can be observed under the microscope. This process also promotes the separation of the aluminum- and iron-hydroxides. Part of these oxides also will be carried away by the ground water, ferric oxide more than alumina. Finally a layer of aluminous concretions is formed with lenses of brown iron ore at its base near the ground-water level.

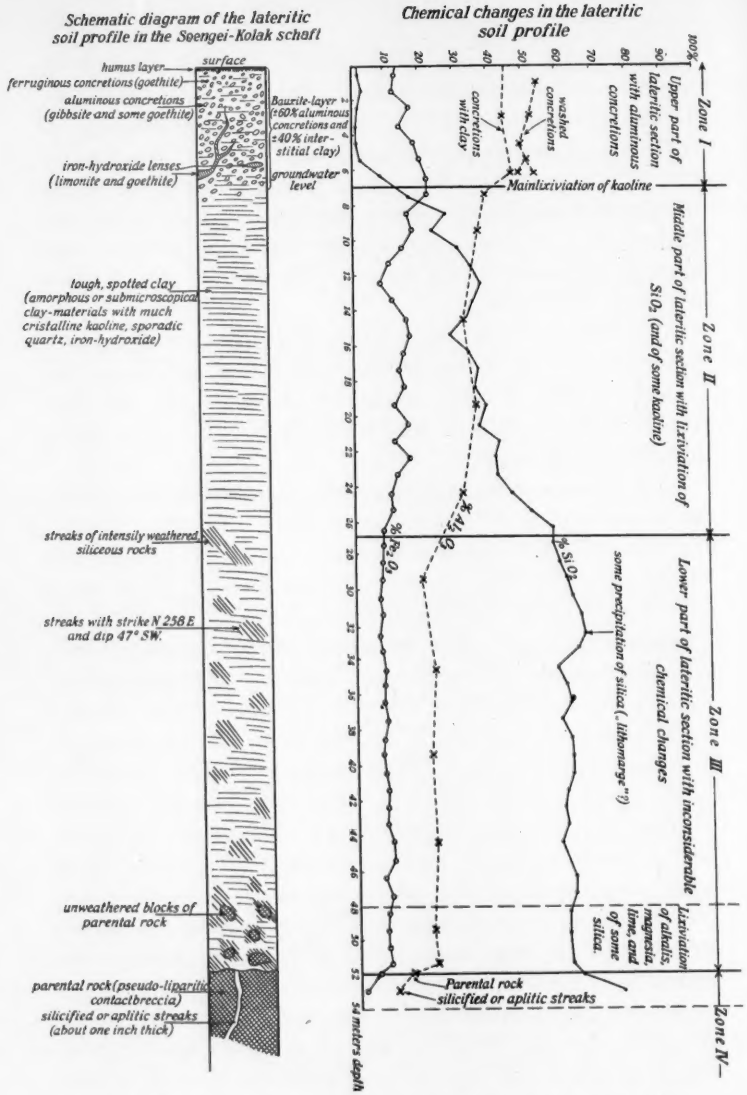
Schematic diagram of the lateritic soil profile in the Soengei-Kolak schaft
surface
humus layer
ferruginous concretions (goethite)
aluminous concretions (gibbsite and some goethite)
Bauxite-layer (±60% aluminous concretions and ±40% interstitial clay)
groundwater level
iron-hydroxide lenses (limonite and goethite)
tough, spotted clay (amorphous or submicroscopical clay-materials with much cristalline kaoline, sporadic quartz, iron-hydroxide)
streaks of intensily weathered siliceous rocks
streaks with strike N 258 E and dip 47° SW.
unweathered blocks of parental rock
parental rock (pseudo-liparitic contactbreccia)
silicified or aplitic streaks (about one inch thick)
Chemical changes in the lateritic soil profile
Zone I
Upper part of lateritic section with aluminous concretions
washed concretions
concretions with clay
Mainlixiviation of kaoline
Zone II
Middle part of lateritic section with lixiviation of SiO2 (and of some kaoline)
Zone III
Lower part of lateritic section with inconsiderable chemical changes
some precipitation of silica (,,lithomarge")
lixiviation of alkalis, magnesia, lime, and of some silica.
Parental rock
silicified or aplitic streaks
Zone IV
54 meters depth

FIG. 3. Diagram of the lateritic soil profile from the bauxite layer downward to the unweathered parent rock.

This bauxite layer is the residue of the selective leaching of the parent rock. Each meter of bauxite concretions is the residue of many meters of parent rock.

EXPLORATION OF BAUXITE IN NETHERLANDS INDIA.

The origin of the Bintan bauxite has been studied in the complete lateritic profile, exposed in the Soengei Kolak shaft. Favorable conditions for the formation of bauxite appeared to be the following:

1. The presence of an argillaceous sediment, relatively rich in alumina, containing free quartz in a finely divided, micro-crystalline stage and, therefore, easily susceptible to leaching.

2. The contact metamorphism, causing the formation of porphyroblasts of plagioclase and amphibole. On weathering, the alumina content of these minerals (anorthite, amphibole) is set free in the form of amorphous aluminum-hydroxide, which, later on, can be concentrated into crystalline gibbsite concretions.

3. The long period of leaching of the lateritic profile during the peneplantation of the Sunda continent.

4. The hornfels of the bauxite fields around Kidjang Strait was surrounded on all sides by granitic intrusions (Figs. 1, 2). The Kidjang Strait region was, therefore, a basin during the peneplanation, wherein hardly any mechanical erosion occurred, and this saved the residual bauxite layers from destruction.

Lateritic alluvial deposits on the top of the Tertiary sandstones and clay shales of Bintan (Fig. 2) appear to be of no value as bauxite ores.

Further exploration of bauxite in Netherlands India should be directed to regions where conditions similar to southeastern Bintan prevailed. Long periods of laterization occurred on the islands of the stable Sunda area, including the western part of West Borneo. In these regions the basins and other flat parts, where little or no mechanical erosion occurred, are the most favorable for the preservation of the aluminous, residual residue. The parent rock must

contain minerals, which, on weathering, produce free aluminum-hydroxide and no kaolinite; such minerals are anorthite, amphiboles, pyroxenes. Moreover, it should be poor in silica or, if the free silica content is high, it should occur in a finely dispersed, easily lateritic state as in the aphanitic hornfels of Bintan. Finally, the primary iron content of the parent rock should not be too high, lest ferruginous laterites should be formed.

BANDOENG, JAVA,
May 27, 1941.

A COPPER DEPOSIT OF THE DUCKTOWN TYPE NEAR THE COEUR D'ALENE DISTRICT, IDAHO.

ALFRED L. ANDERSON.

ABSTRACT.

A copper deposit about 40 miles southwest of the Coeur d'Alene district, Idaho, shows a marked structural and mineralogical resemblance to the copper deposits of the Ducktown type. It occurs as a replacement along bedding plane fractures and fissures in quartzitic beds of the Belt series and its ore consists chiefly of pyrrhotite, chalcopyrite, and lesser cubanite in a silicate and carbonate gangue. Fracturing repeated several times during mineralization caused deposition in three distinct mineral stages, shown by the partial replacement of one group of minerals by later ones. Minerals deposited during the first stage include the silicates (diopside, tremolite, actinolite, biotite, epidote, tourmaline, microcline, and muscovite), and a little quartz; during the second stage, the carbonate (ferriferous dolomite); and during the third stage, the sulphides (pyrrhotite, chalcopyrite, arsenopyrite, and cubanite), and a little quartz and calcite. Except for its mode of occurrence, the deposit possesses most of the characteristic features of a pyrometasomatic deposit but is, nevertheless, a hypothermal deposit formed probably under exceptionally intense temperature conditions.

INTRODUCTION.

THE Mizpah copper deposit, located about 40 miles southwest of the famous Coeur d'Alene mining district in northern Idaho, shows a striking structural and mineralogical resemblance to deposits of the Ducktown type[1] and which, if it were not for its occurrence as a replacement along bedding plane fractures and fissures in quartzite, might well be classed as a pyrometasomatic rather than as a hypothermal deposit. Because the deposit was apparently formed under rather intense temperature conditions and since it possesses many of the characteristic features of the pyrometasomatic group, its occurrence tends to bring out a now

[1] Ross, C. S.: Origin of the copper deposits of the Ducktown type in the Southern Appalachian region. U. S. Geol. Surv. Prof. Pap. 179: 1–165, 1935.

well recognized fact that the only essential difference between the pyrometasomatic and some hypothermal types of deposits may be the character of the rock in which each occurs.

The deposit is in the Hoodoo district in the northeast corner of Latah County, Idaho, and extends across the line of secs. 7 and 8, T.42 N., R.1 W., Boise Meridian, near the head of Mizpah Creek, a tributary of the Palouse River. The Mizpah deposit was selected for description because it is the only one of several that has been developed extensively, and the only one that has shipped ore. The shipments were made in 1918 and include a total of about 262 tons of ore with an average copper content of about 21 per cent.

Some of the features of the deposits were mentioned briefly in an early report by Livingston and Laney [2]; but, although they commented on the resemblance of the deposits to those at Ducktown, Tennessee, and on the presence of minerals suggestive of contact metamorphism, they supplied few mineralogic details and erred in describing the deposits as mineralized sills of hornblende diorite, evidently mistaking some of the intensely altered wall rock for sill-like intrusions of igneous rock.

GEOLOGIC SETTING.

The deposit is contained in siliceous beds of the Belt series (pre-Cambrian). These beds locally have been considerably metamorphosed by emanations from the Idaho batholith, which underlies the area and appears on the surface several miles to the south. Consequently, the light-colored argillites, argillaceous quartzites, and more or less pure quartzites that characterize the series a few miles away are represented by several hundred feet of micaceous quartzite and by not less than 2,000 feet of schistose rocks. The deposit is in the micaceous quartzite at the base of the thick succession of schistose rocks.

Much of the quartzite is grayish, rather fine-grained, and is sprinkled with minute crystals of biotite; but in places the rock has darker bands made up of larger and more numerous grains of

[2] Livingston, D. C., and Laney, F. B.: The copper deposits of the Seven Devils and adjacent districts. Idaho Bur. Mines and Geol. Bull. 1: 92–97, 1920.

this mineral. Minerals other than quartz and biotite are difficult to recognize without the microscope; but some of the beds also have distinguishable grains of feldspar, and, where the feldspar becomes relatively abundant, the quartzite shows transition into gneiss. Most of the quartzite has a faint foliation, but in some of the banded rock this structure is quite pronounced.

Microscopic study shows that some of the quartzitic beds have been more intensely altered than others, perhaps because some of them were more pervious to the igneous emanations than were others. All the quartzite shows evidence of complete recrystallization and the addition of variable but generally considerable amounts of biotite and zircon, and smaller but appreciable amounts of epidote and garnet. Some of the quartzite also contains in addition to these minerals considerable amounts of sodic andesine or albite, albite and microcline, or microline alone. Thus, the quartzite shows incipient to advanced stages of granitization, the narrow granitized layers alternating with layers of the biotized quartzite. In many respects the granitization resembles that observed by the writer in the contact zone of the batholith in another part of the county.[3]

Since the schistose rocks have not been materially affected by the mineralization at the Mizpah, little need be said about them. They differ from the micaceous quartzites in containing much larger amounts of mica and in possessing a much more prominent cleavage or foliation. Much of the schist is garnetiferous and a few miles to the north the garnets are so large and so numerous that several years ago mining of them for use as abrasives was undertaken.

The beds of quartzite and schist are conformable and are tilted to the northwest at angles of 60° to 70°. Apparently they form the flank of a broad anticlinal fold that trends N40°–50° NE., but the structural feature of immediate interest is a broad zone of fracturing that is parallel to the strike and dip of the quartzitic strata and which is made up largely of bedding plane fractures

[3] Anderson, A. L., and Hammerand, V.: Contact and endomorphic phenomena associated with a part of the Idaho batholith. Jour. Geol., 48: 561–589, 1940.

and fissures. This zone of fractures has served as a locus for ore deposition, and movement along it during the course of mineralization has given the deposit some of its most distinctive characters.

CHARACTER AND OCCURRENCE OF THE DEPOSIT.

As pointed out in the introduction, the deposit occurs as a replacement of quartzite; and, except for its mode of occurrence, shows many of the mineralogical and textural features of a pyrometasomatic deposit. It is, however, a hypothermal deposit with a marked resemblance to those of the Ducktown type. Localized along the zone of bedding plane fractures and fissures, it forms a mineralized body 120 feet wide made up of stringers of ore and larger masses aligned for the most part parallel to the bedding. Most of the stringers are too small to be mined alone and too widely spaced to be mined collectively. Only along the hanging wall of the fracture zone where the bedding plane fissures are most prominent are there bodies of ore of appreciable size, the largest composed of massive ore from a few inches to several feet wide bordered in part by disseminated ore of milling grade extending outward in the walls for distances as much as 15 feet.[4] Because much of the deposition has been by replacement of the wall rock, the mineralized seams and bodies are very irregular.

MINERALOGY.

General Features.

The minerals of the deposit include a number of silicates, two carbonates, and a few sulphides. Because of recurrent structural movement and repeated fracturing during the course of mineralization, the minerals were deposited in stages, each stage initiated with a renewed epoch of fracturing. The earliest stage was characterized by the formation of silicates, the second, by the deposition of a carbonate, and the third and final stage, by the deposition of sulphides. These stages may be referred to con-

[4] Livingston, D. C., and Laney, F. B.: op. cit., p. 95.

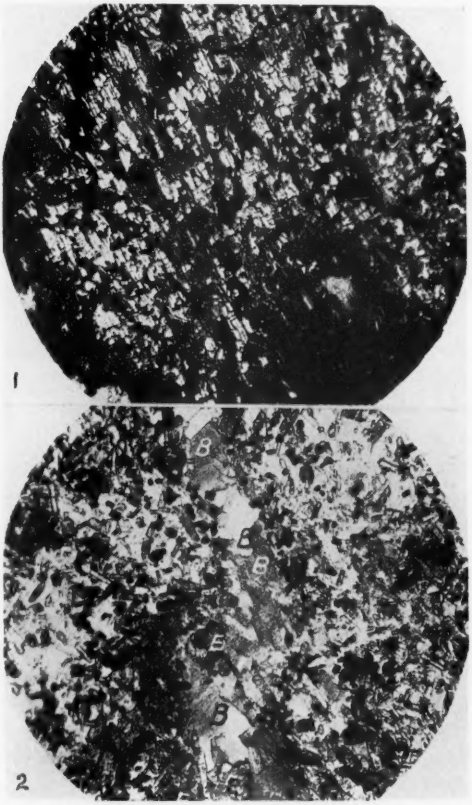

FIG. 1. Photomicrograph of an actinolite crystal (dark) containing remnants of an incompletely replaced diopside crystal (light). Much of the diopside in the deposit apparently has been replaced by amphibole. Crossed nicols. × 35.

FIG. 2. Photomicrograph of the silicate gangue showing a veinlet of young biotite (B) cutting through and replacing an older aggregate of tourmaline (rod-shaped), biotite, and epidote (E) grains in a light-colored quartzitic matrix. The biotite veinlet represents a second-generation biotite belonging to the silicate stage of deposition. Uncrossed nicols. × 35.

veniently as the silicate, the carbonate, and the sulphide stages, the minerals of each partly replacing those of the earlier.

The Silicate Stage.

The minerals of the silicate stage include pyroxene (diopside), amphiboles (tremolite and actinolite), biotite, epidote, tourmaline, microcline, muscovite, and quartz. Only the amphibole and biotite grains are readily distinguished without the microscope, primarily because they are larger and more numerous than the grains of the other minerals. In the more intensely mineralized zones the amphibole crystals are as much as several inches long; but otherwise they are less than an inch, although everywhere larger than the biotite grains, which rarely exceed one-half inch in diameter. Since these two minerals are the most widely distributed as well as the most abundant, they are the ones that largely determine the structure and texture of the ore and give the latter its rather dark color. These minerals are embedded as aggregates in the quartzite along the bedding plane fractures and tend to give the ore and wall rock the appearance of a coarse-grained igneous rock.

Pyroxene.—The pyroxene (diopside) is comparatively rare in the Mizpah ore although relatively abundant in some of the other mineralized zones. Its pale greenish color is rarely observed since, as shown in Fig. 1, it generally occurs as oriented island-like remnant inclusions in the large amphibole crystals. Inasmuch as all stages of replacement by amphiboles may be observed in thin sections, it is possible, since the diopside appears to have been the first mineral formed, that most of it has been changed to or replaced by amphiboles.

Amphiboles.—The amphiboles are the most abundant of the silicates and are exceeded in distribution only by the biotite, which apparently has penetrated somewhat more readily along the bedding and fracture planes at the margins of the mineralized zone than have the other minerals. The *tremolite,* nearly white in color and confined to scattered rosette-like aggregates, is not nearly so abundant as *actinolite.* The latter occurs as slender

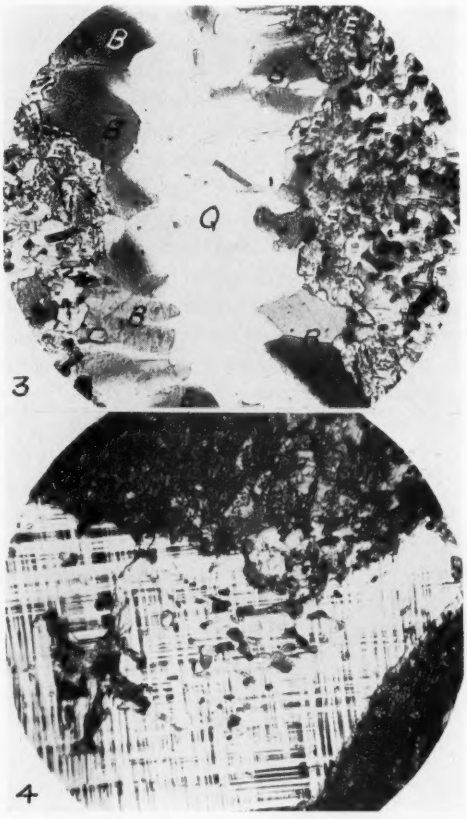

FIG. 3. Photomicrograph of the silicate gangue showing a quartz-biotite veinlet cutting through and replacing an aggregate of epidote (E), tourmaline (rods), and biotite which had earlier replaced much of the original quartzite. The quartz (Q) which forms the center of the veinlet embays and shows some replacement of the biotite (B). It was the last mineral formed during the silicate stage. Uncrossed nicols. × 35.

FIG. 4. Photomicrograph of the silicate gangue showing a large grain of microcline (plaid structure) filling between and embaying into crystals of actinolitic amphibole. Included remnants of biotite, quartz, and epidote appear as small islands in the microcline. Crossed nicols. × 35.

greenish needles, rarely as fibers, and as broad bladed crystals, some of which are several inches long. The large crystals commonly hold scattered inclusions of diopside and also irregular inclusions of the country rock. The actinolitic needles penetrate but do not enclose the minerals of the quartzite.

Biotite.—Most of the biotite grains are about a quarter of an inch in diameter, but, because of their dark color and brilliant luster, they stand out conspicuously in the intensely altered wall rock as well as along the bedding seams in the less altered rock. Grains that were originally present in the country rock remain in part as inclusions in the amphiboles and are not visible, except with the microscope; but those formed during the silicate stage are large and commonly penetrate the amphibole crystals or occur as large grains in the quartzite. Some of the biotite forms veinlets that cut them. There are also some grains of biotite of large size in seams which, as shown in Fig. 2, cut the biotite just described. Whereas the older grains are penetrated and replaced by epidote and tourmaline, these younger grains, as shown in Fig. 3, cut through and replace all three. Only a small amount of this younger biotite appears to be present. In places, the biotite grains have greenish streaks and borders of chlorite.

Epidote.—Most of the epidote grains are large enough to be visible to the unaided eye, but their greenish color makes them difficult to distinguish from the amphiboles. The mineral seems to be relatively abundant throughout the deposit, but its grains are larger and more numerous in the more highly mineralized rock of the hanging wall zone than elsewhere. Some of the original mineral appears as remnant inclusions in the amphiboles. That which has been added by the mineralizing solutions occurs as large grains (Fig. 3) and as clusters of grains, that extend into and through the crystals of amphibole and biotite. These grains are replaced by the younger biotite (Fig. 3).

Tourmaline.—Tourmaline is distributed sporadically through the altered rock always, as shown in Figs. 2 and 3, in rod-like crystals of microscopic size, some of which show green to brown pleochroic colors and others, colorless to blue. In some places

the crystals are so abundant that the rock is black, but in general they are rather widely scattered and wholly invisible, except in thin section. The crystals show some tendency to occur in clusters, especially in the rock where they are most abundant. They commonly penetrate and replace the grains of biotite, except those of the younger generation, and also penetrate and replace the larger grains of epidote. Many crystals also project into included masses of the country rock.

Microcline.—Microcline is present in much of the altered rock, commonly in grains of fairly large size, as portrayed in Fig. 4. These grains cement and in places form veins in the amphiboles and some of the biotite crystals. They also surround and corrode the epidote and early biotite crystals, but relations to the tourmaline are not wholly clear. The microcline may hold inclusions of quartz, plagioclase, and microcline (as shadows) inherited from the "granitized" country rock (Fig. 4).

Muscovite.—Scant amounts of muscovite are found in small, scattered grains in the altered rock associated closely with the microcline, commonly as pseudomorphs after biotite. Its grains are generally no larger than those of biotite and are distinguished with difficulty from bleached and weathered grains of the latter.

Quartz.—Small amounts of quartz also appear in association with the silicates. It generally forms lobe-like grains which, as shown in Fig. 3, embay the minerals of the silicate stage. This quartz is to be distinguished from some that is younger; for, whereas it shows evidence of replacement by carbonate belonging to the second stage of deposition, the younger replaces the carbonate.

Paragenesis.—The minerals of the silicate stage have been formed in a fairly well-defined sequence as determined largely from successive replacements. The succession from the earliest to the latest seems to be diopside, tremolite and actinolite, biotite, epidote, microcline, tourmaline (?), biotite (?), muscovite, and quartz. This is a succession which conforms closely with Bowen's reaction series.

The deposition of a little quartz apparently ended the first stage of mineralization. Not until the mineralized zone had been disturbed by renewed movement along the bedding plane fractures and fissures was mineralization resumed and the second stage initiated. The disturbance reopened most of the original fractures along the bedding planes, but the fracturing was slight, except near and along the hanging wall where the movement was accompanied by rather extensive brecciation of the silicates and quartzite.

The Carbonate Stage.

Dolomite (ferriferous).—A carbonate was the only mineral deposited during the second stage. It contains considerable amounts of magnesia and iron as well as lime, but, since chemical analyses show more magnesia than iron, the carbonate is a ferriferous dolomite and not an ankerite.

The carbonate has penetrated throughout the mineralized zone, even into the fractures that had received little, except biotite. It not only has penetrated irregularly into the silicates, as shown in Fig. 5, but also in places it has entered the quartzite. Through much of the mineralized zone it has gone into the silicates in such a way as to make it resemble the light-colored grains of a dark coarse-grained igneous rock; but locally it forms light-colored streaks through the darker silicates and, in the breccia zones, a light-colored cement surrounding but also penetrating the silicate and quartzite fragments. The carbonate has replaced the earlier minerals extensively, the presence of the original silicates in places being revealed as ill-defined shadows and as small irregular inclusions (Fig. 5).

The deposition of the carbonate apparently put a halt to further deposition until refracturing, less severe than the preceding, reopened the channels and made way for the third surge of the mineralizing solutions. Again the reopening was along the original bedding plane fractures, the more extensive and conspicuous reopening, as before, taking place along the fissures in the hanging wall zone.

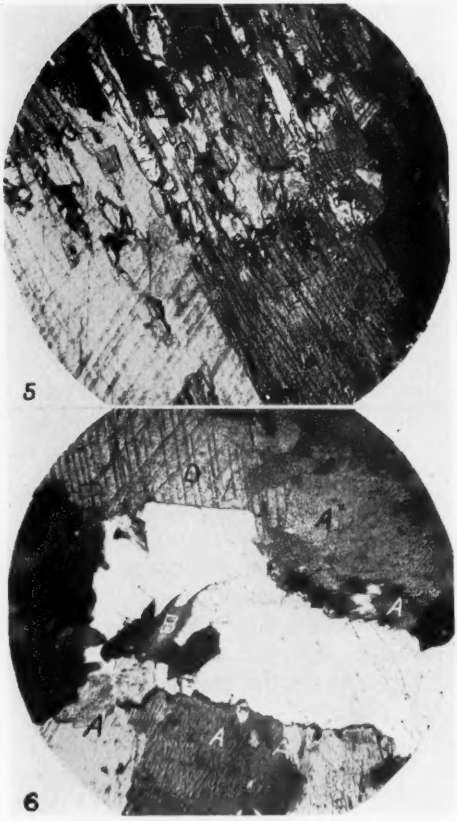

FIG. 5. Photomicrograph showing a large grain of ferriferous dolomite (light gray) penetrating irregularly into and replacing a crystal of actinolite (dark gray). Much of the actinolite appears in the dolomite as oriented, island-like remnants. Replacement of silicates by carbonate has been extensive. Crossed nicols. × 34.

FIG. 6. Photomicrograph showing a veinlet of the late quartz associated with the sulphide stage of deposition cutting across grains of amphibole (A), embaying biotite (B), and by replacement impressing its own crystal outline against a grain of ferriferous dolomite (D). Crossed nicols. × 34.

The Sulphide Stage.

The minerals of the third or sulphide stage include large amounts of pyrrhotite, a little arsenopyrite, about as much chalcopyrite as pyrrhotite, considerable cubanite, and a little quartz and calcite. These minerals have penetrated widely through the deposit, the chalcopyrite having advanced farther along the fractures and deeper into the altered rock and the quartzite than have the pyrrhotite and other minerals. In places the pyrrhotite and chalcopyrite form irregular veinlets in the dolomite and silicates; in other places, disseminated grains and small irregular masses. In the main fissure of the hanging wall zone the sulphides form bodies of almost massive ore that contains only scattered inclusions of the gangue. The deposition has taken place almost entirely by replacement. Apparently the silicates and the ferriferous dolomite were replaced with equal ease since about as much ore occurs in the one as in the other.

Pyrrhotite.—Much of the pyrrhotite when viewed in polished surfaces shows a somewhat platy structure and a more or less prominent twinning. Many of the grains are apparently distorted and give wavy polarization colors. In places the grains are considerably fractured, the fragments cemented by chalcopyrite; but generally, though distorted, they are not crushed. Many of the smaller grains are held as rounded bleb-like inclusions in the chalcopyrite.

Arsenopyrite.—The arsenopyrite in small amounts is widely scattered along the mineralized zone. Locally it appears in small lenses and veinlets that cut pyrrhotite. Some of the crystals are much shattered, the fragments held in a cement of chalcopyrite.

Chalcopyrite.—All of the chalcopyrite shows a fairly prominent multiple twinning when viewed in reflected polarized light. It commonly holds remnant inclusions of pyrrhotite and it is possible that it has replaced half of the pyrrhotite originally deposited along the hanging wall fissure.

Cubanite.—Considerable cubanite in intergrown blades or laths is contained in the chalcopyrite, the blades occurring in scattered bands that cross the twinning lines of the chalcopyrite. The

cubanite occurs only in the chalcopyrite that is in contact with pyrrhotite and may be a product of unmixing.

Quartz and Calcite.—The little quartz associated with the sulphides was deposited first, since in places the spaces between the quartz crystals are filled with the sulphides. On the other hand, the calcite was deposited last, because it occurs as a filling of small fractures in the sulphides. The quartz associated with the sulphide stage of deposition cuts and replaces the earlier silicates and ferriferous dolomite, in part impressing, as shown in Fig. 6, its own crystal outline against the carbonate.

Paragenesis.—The mineral succession during the third and final stage of mineral deposition is well established. Beginning with the deposition of scant amounts of quartz, there followed pyrrhotite, arsenopyrite, chalcopyrite and cubanite, and at the end a little calcite. From the evidence of distortion and mashing of some of the pyrrhotite and crushing of the arsenopyrite, it is apparent that there was some structural movement concurrent with deposition during early sulphide deposition. This movement may have facilitated the introduction and widespread distribution of the chalcopyrite.

Secondary Minerals.

The deposit contains a number of minerals derived from the sulphides by supergene processes. Among these secondary minerals are marcasite after pyrrhotite, chalcocite after chalcopyrite and cubanite, much fibrous malachite, some azurite, considerable cuprite, and much limonitic iron oxide. These minerals are abundant near the surface but scarcely reach to depths of more than 25 feet.

GENESIS OF THE DEPOSIT.

As already pointed out the deposit is a replacement deposit formed by the deposition of ore along a zone of fracturing in somewhat granitized quartzite. It has also been shown that the deposition of ore was not continuous during the period of mineralization, but that it was interrupted several times by plugging

of the ore channels and was resumed only after an epoch of fracturing had reopened the channels. Consequently, the mineralizing solutions were fed to the fracture zone three different times and the ore was deposited in three stages. Since an interval of some duration apparently intervened between each of these stages, there was opportunity for further differentiation at depth, and each surge introduced solutions of different composition.

Composition of Solutions.—The first ingress of mineralizing solutions carried and added to the country rock considerable amounts of calcium and magnesium, and lesser but variable amounts of iron, aluminum, potassium, fluorine, and boron. At the temperatures than existing the elements entered into various combinations with silica to form the sequence of silicates by replacement of the country rock. The minerals were formed in a sequence apparently determined by temperature and conforming closely with Bowen's reaction series for the igneous rocks. These gangue minerals may be a record of events in the intermediate stages between the pyrogenic processes of differentiation and the later stages of the same process that gives rise to ore minerals.

The second surge of solutions apparently brought in little except calcium and lesser amounts of magnesium and iron; but instead of combining with silica to form silicates, they joined with carbon dioxide to form a ferriferous dolomite and were deposited largely by replacement of the silicates. Just how these elements were carried in solution and why they did not combine with silica to form silicates are questions that must remain unanswered at present.

During the third and final stage of mineralization the solutions carried in iron and copper along with sulphur and a little arsenic and, largely by replacement of the earlier minerals, deposited pyrrhotite, arsenopyrite, chalcopyrite and cubanite. The cubanite was probably a product of exsolution. Small amounts of quartz and calcite were also deposited. Aside from the presence of heavy metals, sulphur, and a little arsenic, there is nothing to indicate the chemical character of the solutions.

Temperature of Solutions.—That the solutions possessed a high degree of heat during the first ingress into the fracture zone is indicated from the early deposition of pyroxene, amphiboles, and other silicates. Normally, most of these minerals belong to the pyrogenic and late magmatic stages of consolidation of magmas, and the fact that they appear in a hydrothermal sequence must indicate that solution temperatures were high at the time of deposition. Just what the temperatures were during the carbonate stage of deposition cannot be conjectured; but they must still have been relatively high during the sulphide stage as indicated by the relative abundance of cubanite, a mineral which is believed to form only at high temperatures. Both pyrrhotite and cubanite are found rather characteristically in pyrometasomatic and hypothermal deposits. Probably the temperatures were high throughout the period of mineralization but were somewhat lower during the sulphide than during the early silicate stage of formation.

Source and Age.—The source of the mineralizing solutions might well have been the Idaho batholith whose emanations had already impregnated the country rock with more or less biotite, zircon, epidote, and feldspars; and it would be only logical to suppose that the mineralizing solutions had been derived somewhat later than the emanations from a deeper part of the consolidating and differentiating magma body. However, the wall-rock alteration shows such a marked resemblance to the alteration associated with the emplacement of a monzo-syenite stock in the Gold Hill district 12 miles to the west (a resemblance also noted by Livingston and Laney[5]), that much doubt must exist as to whether the Idaho batholith is the actual magmatic source. In fact, the similarity of the alteration to that in the Gold Hill district is so striking that there can be little doubt of a genetic relationship, which leads to the belief that the magma of monzonitic and syenitic composition was the actual source of the mineral-bearing solutions. Since, for reasons to be discussed in a future paper, the writer considers the Gold Hill stock, like the similar syenitic and monzonitic bodies in the Coeur d'Alene district, to be

[5] Op. cit., p. 97.

products of early Tertiary igneous activity and not differentiates of the Idaho batholith (Cretaceous),[6] the Mizpah mineralization is probably early Tertiary rather than Cretaceous.

ECONOMIC FACTORS.

The deposit has been opened along several drifts and cross cuts to depths of not more than 200 feet below the surface. Ore near the surface was rich enough to be shipped without milling, and the entire production came from the shallow oxidized and sulphide enriched zone. Apparently the operators found it unprofitable to stope in the primary ore below.

The development has demonstrated that the commercial ore is confined to relatively small bodies close to the hanging wall of the mineralized zone. Although considerable copper remains in the deposit, whether it can be recovered profitably or not depends largely on improvement of prices and economic conditions.

CONCLUSIONS.

Were a collection of the Mizpah ore and gangue minerals to be examined without knowledge of field conditions and without close attention to the actual mineral relations, one might conclude that the ore was obtained from a pyrometasomatic deposit, which in view of the coarseness of grain had been formed under conditions of exceptionally high temperature. However, the field relations show that the deposit is not pyrometasomatic; but, like the deposits of the Ducktown type, is a replacement of non-calcareous rock.[7] In this case it is a replacement of somewhat "granitized" quartzite, and a hypothermal deposit probably formed at temperatures comparable with those at which most of the pyrometasomatic deposits have been formed. It also is related genetically to a deep-seated magma, one probably younger than the Idaho batholith which caused the general metamorphism of the

[6] Reed, J. C.: Geology and ore deposits of the Warren mining district, Idaho. Idaho Bur. Mines and Geol. Pamph. 45, p. 8, 1937.

[7] U. S. Geol. Surv. Prof. Pap. 179, op. cit., pp. 24–38.

country rock. Because there is no appreciable difference between the Mizpah deposit and those of pyrometasomatic origin, except in the character of the rock replaced, the occurrence may justify the statement that the pyrometasomatic may be a special case of the hypothermal in which the wall rock happens to be an easily replaceable carbonate rock.

Acknowledgments.—The writer wishes to acknowledge his gratitude to Professor H. Ries for his reading of the manuscript.

CORNELL UNIVERSITY,
ITHACA, NEW YORK,
April 1, 1941.

DISCUSSION AND COMMUNICATIONS

ALBITE AND GOLD.

The paper by David Gallagher in the September, 1940, number of this journal suggests a genetic relationship between ore deposits where gold is the only valuable metal and other metallic minerals are not abundant, and igneous rocks rich in albite. Field examples are presented to support this thesis; some " exceptions " are listed. The present discussion deals with a fundamental assumption of the paper, and adds a few " exceptions."

What is the proof of genetic relationship between an ore deposit and an igneous rock or a rock-forming mineral, in this case albite? Obviously, where albite occurs in the gangue of an ore deposit evidence for genetic relationship between the albite and the ore is stronger than where the deposit merely occurs in or near an albitic igneous rock. It may be doubted, however, that albite in the gangue of a gold deposit necessarily came from the same ultimate source as the gold associated with it. In nearly all the examples of vein albite cited by Gallagher, albitic rocks are found in the district:

District or Mine.	*Albite in the Gangue* (or as product of hydrothermal alteration).	*Albitic Intrusives Present.*
Siscoe Mine, Que.	X	X
Porcupine, Ont.	X	X
St. Anthony Mine, Ont	X	X
Rice Lake-Gold Lake, Man.	X	X
Argosy Mine, Ont.	X	
Treadwell Mine, Alaska.	X (?)	X
Lardeau Map-area, B. C.	X	X
Alleghany, Calif.	X	X
Alamo, Baja Calif.	X	X
Bendigo, Victoria.	X	No pre-mineral intrusive

For Porcupine, Gallagher quotes Hurst as suggesting that the early deposition of albite in the veins "may be related to the hydrothermal alteration of wall rocks that are relatively rich in soda."

That hydrothermal solutions are capable of extracting soda from the rocks they attack is shown by Schwartz[1] who says: "Composite diagrams as well as the averages show that soda is usually lost during the hydrothermal alteration of igneous rocks. The percentage of loss is least in the basic rocks, which are low in soda to start with." It is quite possible that albite and gold in an ore deposit derive from a common source; but where albitic intrusives occur, definitely older than the ore deposits in their neighborhood, the chance that soda was extracted from these intrusives below the zone of observation, and redeposited in the veins as albite must not be underemphasized. The presence of albite in a vein where albitic rocks abound is no proof of genetic relationship between the albite and the gold now found associated with it.

If the presence of albite in the vein is no proof, what of mere spatial association between gold veins and rocks containing albite? Spatial relations are of two kinds: an intimate association, e.g. a gold vein along one wall of an albitic dike, and broad, statistical relationships, e.g. the common presence of albitic intrusives in gold districts of the kind described by Gallagher.

In the case of the gold vein along an albitic dike (intimate association), there is some reason for suspecting a genetic relationship between the dike and the vein, because their emplacements may be closely linked in *time* as well as space. The present writer thinks that most dikes and veins not formed by replacement (and possibly some that were) were emplaced while their fissures were opening. A vein along an older dike implies reopening of part of the dike fissure, and suggests recurrence of the forces that opened the fissure in the first place. While such recurrence may have taken place at a different tectonic period, the forces of which

[1] G. M. Schwartz: Hydrothermal alteration of igneous rocks. Bull. Geol. Soc. Am., 50 (1939), 224.

bear no relation to those of the first period, there is at least some *a priori* reason for thinking the reopening due to spasmodic activity of the same set of forces that opened the dike fissure to begin with. If so, dike and vein may be closely linked in time of formation, and since they used the same channel, may have a genetic relationship.

But of what special value are Gallagher's examples of gold veins that are deposited in albitic portions of intrusive complexes otherwise non-albitic? (Coast Range of Alaska and Canada, 708, Skeena River District, 708, Bridge River District, 709, Zaruma [not Zaruna] District, Ecuador, 715, etc.). Few geologists can still be found who think such veins came directly from the albitic rocks near or within which they are found, so that this type of areal association has little bearing on a possible genetic relationship other than to stress the fact that veins and albitic intrusives are in the same district.

But what of that? Is the fact that a certain type of intrusive and a certain type of vein are often found together proof of their genetic relationship? Advocates of the magmatic differentiation hypothesis for ore deposits would say so, although since several intrusive types generally occur in a mining district, different advocates might select different intrusive types to link with the ore deposits. Schmitt [2] cautions against the assumption that this hypothesis is as far advanced toward proof and unquestioning acceptance as some suppose. The hypothesis is primarily based on the common association of ore deposits with igneous masses of intrusive origin. To treat it as an hypothesis is one thing; to accept it as a basic postulate should follow only after critical study and rejection of all other theories that might explain the field relations upon which the magmatic hypothesis is built.

I present, briefly, an alternative hypothesis, with no attempt at supporting evidence, but merely to show that the association of ore deposits with intrusive massives might be explained otherwise than by magmatic differentiation.

[2] Harrison Schmitt: Mining Geology (Annual Review). Eng. & Min. Jnl., 142 (1941), 77–79.

Gallagher's basic assumption as understood by the present writer is this: many ore deposits are late products of differentiation from magmas that solidified, not at some great telluric depth, but so high in the crust that their offshoots, within or near which the ore deposits are being mined, are "a representative sample of the igneous rock that was the parent of the ore-bringing solutions" (701).

There is evidence at hand that massives, for the most part originally intrusive in character, are favored loci for repeated uplifts, some of which took place geologic epochs later than the intrusion. Possibly both the massive and the softer rock surrounding it are in such cases uplifted by vertical forces active over a wide region; but the hard igneous "wart" domes the sediments or flows above and around it, and fractures them in characteristic patterns, so that uplift effects are accentuated around the "warts."

A number of mining districts seem to be "genetically" associated with uplift. Their vein fractures resulted from stretching of the crust by doming or arching, and the vein matter entered the fractures while this tensional pull kept them open. Since fractures due to uplift are best developed near igneous massives, the hypothesis explains the frequency of ore deposits around and above such massives, and their sparseness within the massive itself. It explains also something the magmatic theory, which requires a granitoid intrusion as its *modus operandi,* cannot explain, i.e. great mining districts such as the Tri-State District and certain of the manto deposits of Mexico, where no major intrusive masses linked in time with the mineralization have ever been found.

Many mining districts appear related to horizontal forces active at about the time of the mineralization. Here again the areal association of ore deposits with granitoid massives can be explained structurally without any assumption that the ore deposits came from the massive or its close cousin at comparatively shallow depth. It follows that the statistical association of ore deposits with stocks, bosses, cupolas and the like is no water-tight proof of genetic relationship in the sense used by Gallagher. Few

would deny that regions of ore deposits are commonly regions of active and variegated intrusion as well; but it is unsafe as yet to go much beyond that generalization, and doubly unsafe to assume that the magmatic hypothesis based on it is a proven fact.

If the gold deposits mentioned by Gallagher had some source far-separated from that of his albitic intrusives, then any association of the two is more or less coincidence. Field evidence for his thesis may be so overwhelming that the notion of coincidence must be rejected. As Gallagher says, the presence or absence of albite in a critical district is seldom known, so that the present writer can add but a few such districts to the evidence, and comment on only one mentioned by Gallagher.

Gallagher adds two corollaries to his principal thesis, which is the genetic relationship between gold deposits poor in other metallic minerals, and albitic intrusives. The first corollary is this: "Where silver is more abundant, the lime content of the feldspars of the associated igneous rock is higher" (699). At Pachuca, Mexico, the ratio by weight of silver to gold is uniformly about 200 to 1. No granitoid intrusives are exposed. The wall rocks of the veins are mainly porphyritic augite andesite flows; the plagioclase is andesine-labradorite. Albitization of the feldspar is an important feature of the hydrothermal alteration in the vicinity of the veins, and is a guide to ore. Base sulphides occur very sporadically at Pachuca, abundant in parts of some veins, sparse in others.

Gallagher's other corollary is as follows: "Where silver is in considerable excess over gold, or where gold is subordinate to other metals, or where other metallic minerals are very abundant, soda feldspars are generally lacking, and not uncommonly the genetically related igneous rocks are notably potassic." There seems to be a confusion in thought concerning commercial importance of a metal in contradistinction to the weight of it present in relation to the weight of other metals present; in the cleanest "siliceous gold ore," gold is probably nearly always subordinate to base sulphides, by weight. Try panning such an ore. But I take this generalization to mean, for one thing, that gold deposits

where base sulphides are abundant are not associated with albitic igneous rocks.

Gallagher offers the José Pañganiban district (western portion of the Paracale district) in the Philippines as an example of the association of ore deposits where gold is the only valuable metal and other metallic minerals are sparse, with albitic intrusions (724). The Paracale gold veins are found in albite granite, and many lie alongside "consanguineous albitic dike rocks." Unfortunately, the Paracale gold veins are decidedly polymetallic, so much so that flotation concentrates go to a copper smelter; galena and sphalerite are even more abundant than chalcopyrite.

On the other hand, the Baguio district in the Philippines offers a perfect example of the type of ore deposit where gold is the only valuable metal, and other metallic minerals are sparse, except in a few veins. The principal igneous rocks of the district are quartz diorite and andesite. The feldspars of the quartz diorite are oligoclase, grading to somewhat more calcic types, or andesine-labradorite.[3] If albite has ever been identified in the district, the fact has escaped my knowledge.

It seems to me, in summary, that the basic assumption of this paper is debatable, and that certain clear-cut field examples with which I am familiar directly contradict the principal generalizations proposed.

EDWARD WISSER.

SAN FRANCISCO, CALIF.,
April 2, 1941.

VEIN-FORMING SOLUTIONS.

Sir: In reviewing the literature on vein-forming solutions, I have been impressed by the number of references to dilute alkaline solutions as a medium of metal transport in the origin of hydrothermal mineral deposits. This is surprising in the light of the fact that, on theoretical grounds, metal sulphides reach their minimum solubility in such an environment.

[3] Andrew Leith: Geology of the Baguio gold district. Dept. of Agriculture and Commerce, Manila, Tech. Bull. No. 9 (1938), 23.

So far as I can discern, the postulation of dilute alkaline solutions has grown from two misconceptions; (1) the mistaken assumption that sulphides carried as colloids are in true solution, and (2) unjustified analogies between concentrated and dilute solutions.

In spite of Lindgren's conclusions[1] it is apparently agreed by many economic geologists today that colloids do not play an important role in hypothermal or mesothermal deposits.[2] In any theory of transfer in a fluid, absence of colloids necessitates that the sulphide be in true solution. Several metals, including at least lead, copper, and silver, are almost completely *insoluble* in alkaline liquids of any concentration, although a colloidal form is easily obtained.[3] Zinc is an exceptional case.

The metals that are truly soluble in alkaline solutions, such as mercury, arsenic, and antimony, are soluble because they form a complex of the form $MeS_2^=$.[4] The formation of these complexes demands an *excess* of sulphide ion to force the sulphide into the soluble form, as shown by the law of mass action. If one of these metal sulphides is put into an alkaline solution, and sulphide ion is added, the first effect is to decrease the solubility of the metal sulphide because of the common ion effect. As more sulphide ion is added, the solubility of the metal sulphide will eventually begin to increase as it is forced into the complex.

The concentration of sulphide ion necessary for this reversal of the solubility curve depends, of course, on the solubility products of the sulphides and on the ionization constants of the complexes, which are apparently unknown; but from analogies with chloride complexes,[5] a concentration of at least 0.3 to 0.4 molal

[1] Lindgren, Waldemar: Mineral deposits. McGraw-Hill Book Co., New York, 1933, p. 190.

[2] Graton, L. C.: The nature of the ore forming fluid. Econ. Geol., 35 (supplement): 212, 1940.

[3] Schmedemann, O. C.: Notes on the chemistry of ore solutions. Econ. Geol., 33: 788, 1938.

[4] Dreyer, Robert: The geochemistry of quicksilver mineralization. Econ. Geol., 35: 28, 1940.

[5] Kendall, James, and Sloan, C. H.: Solubility of slightly soluble chlorides in concentrated chloride solutions. Jour. Am. Chem. Soc., 47: 2309, 1925.

excess sulphide ion is necessary before the *minimum* solubility point is reached.

A solution 0.3 to 0.4 molal in sulphide ions alone can hardly be called dilute, yet in solutions of smaller concentration, the solubility of the metal sulphides is infinitesimally small.

Therefore, since some metals do not form true solutions in an alkaline medium, and those that do require high sulphide ion concentrations, it seems that dilute alkaline solutions are a very poor medium for ore transport. These statements are, of course, based on chemical evidence, but it would seem as though very strong geologic evidence would be required to maintain a contrary viewpoint.

ROBERT GARRELS.

EVANSTON, ILLINOIS,
May 1, 1941.

REVIEWS*

Geological Investigation of the Chromite Deposits of California. By J. E. ALLEN. Pp. 68; figs. 31. Cal. State Min. Report XXXVII; 101–167, 1941.

This bulletin describes the chromite deposits of California. It has more than regional significance, however, because its author, in the first chapter, discusses the origin of chromite. This discussion is unique among studies of chromite, so far as the reviewer knows, in that the discussion of origin is based on an analysis of the larger structural features of chromite ore bodies and groups of ore bodies rather than on the petrographic features of individual deposits. All the localities described, some 234 in number, are classified according to six major structural features—(1) number of ore bodies, (2) size of ore bodies, (3) shape of ore bodies, (4) attitude of major axes of ore bodies, (5) degree of serpentinization of country rock, and (6) structure within the ore. Deposits, even though they be adjacent and in the same group, that lie more than a quarter of a mile apart are counted as separate localities.

The author's main conclusions are as follows:

(*a*) "With one exception none of the chromite deposits studied could, on the basis of microscopic evidence, be definitely placed in the category of magmatic segregations in place." (*b*) "Although differentiation of chromite may begin before intrusion it is more likely that it takes place during and even after intrusion.

"As soon as the margins of the intrusion solidify, compressive stresses establish well-defined zones of strain in parallel or intersecting sets of faults.

"Movement along these fault zones permits introduction of chromite-rich "crystal mush," or hydrothermal solutions. The process may be initiated while differentiation is still active, or while the solutions are becoming more and more highly concentrated.

"Stresses along many of the fault zones may result in gash-joint openings in en echelon series, producing the overlapping lenses of high-grade ore.

* Books noted under *Reviews* and *Books Received* may be ordered through the Economic Geology Bookshop, W. S. Bayley, Urbana, Ill., but orders for official reports and single copies of Journals should be sent directly to their publishers.

"The large ore bodies are most frequently found at the intersection of the fault zones, as in other types of mineralization.

"Most of the chromite ore bodies thus seem to have been emplaced late in the magmatic cycle, after partial consolidation of the rock and contemperaneous with the early deuteric activity of the magma. The period of their emplacement reached a maximum before or soon after the beginning of serpentinization. In a few cases the ores seemed to be syngenetic with unaltered including rock, and rarely are late hydrothermal and post-serpentinization."

Earlier in the chapter he says: "A study of the large-scale structural relationships of the West Coast deposits seems to bear out in most essentials, with evidence from an entirely different direction, the conclusions of Fisher and Sampson." These writers advanced the hypothesis that a substantial part of the constituents of the chromite passes into residual solutions, which may be highly aqueous and capable of migrating for considerable distances, and that chromite deposits are formed from these solutions.

Allen's emphasis on linear structural control results from a method of analysis, consequent on the arbitrary method of defining a locality, that gives a distorted picture of structural regularity. If the chromite bodies within each intrusive mass are compared, a bewildering complexity of structure is frequently found. Though the reviewer, who has examined many of these deposits, recognizes linear structural control, especially in the lenses of homogeneous chromite, he finds that chaotic structures are so common and so large as to indicate that much of the chromite was not emplaced along lines of fracture. Furthermore, although he agrees that the chromite cannot be regarded as a magmatic segregation in place from the present enveloping ultrabasic body, he believes that the preponderance of evidence indicates that most of the chromite is a pyrogenic mineral, that it crystallized from a melt, and that the crystals of chromite were concentrated and then injected, either with or into the ultrabasic body in which it is now found. In some deposits the chromite-rich mush was introduced as part of the original intrusion of the ultrabasic body; in others it was injected into earlier-emplaced but not yet wholly solidified magma by a later intrusive pulse; and in still others it was intruded into ultrabasic rock that was rigid enough to fracture.

Most of the chromite had crystallized prior to intrusion. Though some slight rearrangement of the chromite may have been effected by hydrothermal solutions, no significant amount of chromite was precipitated from hydrothermal solutions that had transported the constituents of chromite, as solutes, from afar.

This bulletin is an interesting pioneer in a new approach to the study of the origin of chromite.

F. G. WELLS

Outlines of Physical Geology, 2nd Edit. By C. R. LONGWELL, A. KNOPF, AND R. F. FLINT. Pp. 381; figs. 281. John Wiley and Sons, New York, 1941. Price, $2.75.

This edition, like its predecessor, is an abridgement of the new 1940 edition of the larger volume, "Textbook of Physical Geology," and is a continuation, through several editions, of the original "Outlines" by Pirsson and Schuchert. It contains, in restricted form, the additions and revisions of the "Textbook." The introductory chapter has been recast into a 10-page "Preview of Geology" or abstract. A new final chapter, "History, the Central Theme of Geology," sums up geologic processes as agents of change and emphasizes the historical nature of geology. Mass wasting is given emphasis and simplifications are noted in the bringing together of volcanoes and igneous bodies, a combination of minerals and rocks, and in the simplicity of terminology. Many striking new illustrations will be seen, and a striking innovation is the inclusion of some 40 new "bled" halftones, of full-page width, some of which are stunning.

Field Geology. By F. H. LAHEE. 4th Edit. Pp. 853; figs. 589. McGraw-Hill Book Co., New York, 1941. Price, $5.00.

This well known and useful book has undergone rather complete revision and considerable enlargement. There are 61 new figures; new material is added on mass movements, varves, lensing strata, permeability, flow structure and preferred orientation of mineral constituents of rocks, folds and faults. The section on airplane mapping has been enlarged and that on geophysics has been entirely rewritten; electrical logging and subsurface correlation by radioactivity have been included.

The excellent features of the book that have made it a necessary text for every student of geology have been retained and, as would be expected, the new developments of petroleum field methods have been included. The volume should continue to be the outstanding book on field geology.

Done in Oil. By D. D. LEVEN. Pp. 1084; illust. Ranger Press Inc., New York, 1941. Price, $10.00.

This voluminous popular book is intended to meet the need of the general public interested in the present and future welfare of the oil industry as a whole. It is written from a practical, economic, and financial viewpoint. It deals with the history of oil, economic supplies and reserves, major fields, international situation, finding and producing, transportation, refining and marketing, finance and investments, royalties, securities and markets, taxation, and ends with a glossary and appendices. Geology is subordinate. The volume contains much valuable material for the general reader.

American Influence in Canadian Mining. By E. S. MOORE. Pp. 144. Univ. of Toronto Press, Toronto, Canada, 1941. Price, $2.25.

This book is No. 9 of a Political Economy Series. It deals with the development of the various mining industries of each district in each Province, and with "Capital, Equipment and Technique," "Labour," and "Industry and Trade."

BOOKS RECEIVED.

WILLIAM E. BENSON.

Chromite Deposits in the Seiad Quadrangle, Siskiyou County, California. G. A. RYNEARSON AND C. T. SMITH. Pp. 25; pls. 5; figs. 4; geol. map 15″ × 20″, scale 1″ = 500 ft. U. S. Geol. Surv. Bull. 922–J. Washington, 1940. Price, 30 cents.

Quicksilver Deposits of the Mayacmas and Sulphur Bank Districts, California. C. P. Ross. Pp. 26; pls. 7; 6 geol. maps of varying sizes and scales. U. S. Geol. Surv. Bull. 922–L. Washington, 1940. Price, 45 cents.

Chromite Deposits of the Eastern Part of the Stillwater Complex, Stillwater Co., Mont. J. W. PEOPLES AND A. L. HOWLAND. Pp. 45; pls. 3; figs. 15; tables 4; 2 geol. maps, scales 1″ = 1 mile, and 1″ = 400 ft. U. S. Geol. Surv. Bull. 922–N. Washington, 1940. Price, 40 cents.

Chromite Deposits of the Pilliken Area, Eldorado Co., Cal. F. G. WELLS, L. R. PAGE, AND H. L. JAMES. Pp. 43; pls. 4; figs. 3; all plates and figs. are geol. maps. U. S. Geol. Surv. Bull. 922–O. Washington, 1940. Price, 35 cents.

Tungsten Deposits in The Tungsten Hills, Inyo County, California. D. M. LEMMON. Pp. 17; pls. 6; figs. 2; 2 geol. maps, scale 1″ = 500 ft. U. S. Geol. Surv. Bull. 922–Q. Washington, 1941. Price, 20 cents.

Tungsten Deposits of the Benton Range, Mono County, California. D. M. LEMMON. Pp. 13; pls. 2; figs. 2; geol. map in color, 14″ × 19″, scale 1″ = 200 ft. U. S. Geol. Surv. Bull. 922–S. Washington, 1941. Price, 30 cents.

Supplement to Geology and Ground-Water Resources of Oahu, Hawaii. H. T. STEARNS. Pp. 164; pls. 6; figs. 8. U. S. Geol. Surv., Hawaii Terr. Bull. 5. Honolulu, 1940. Describes progress in development since Bull. 1 (1935). Includes chapters on geophysics by J. H. Swartz, and petrography by G. A. Macdonald. *Excellent photographs and diagrams.*

Water Levels and Artesian Pressure in Observation Wells in U. S. in 1939. O. E. MEINZER, L. K. WENZEL, AND OTHERS. Pp. 933; figs. 34. U. S. G. S. W. S. P. 886. Washington, 1940. Price, $1.00. *Statistical.*

The Pictou Coalfield, Nova Scotia. W. A. BELL. Pp. 160; pls. 10; figs. 1; geol. map in color, 15″ × 30″, scale 1/24,000. Canada Dept. Mines and Res., Geol. Surv. Memoir 225. Ottawa, 1940. Price, 50 cents. *Detailed report covering paleontology, stratigraphy, structural and economic geology, and mining history of the region.*

SCIENTIFIC NOTES AND NEWS

The first PAN-AMERICAN CONGRESS OF MINING, ENGINEERING, AND GEOLOGY will be held at Santiago de Chile the first two weeks of January, 1942, under the auspices of the Chilean Institute of Mining Engineers. Papers on geology, mining, ore dressing, and metallurgy, limited to 15,000 words, in Spanish, Portuguese, or English, the official languages of the Congress, must be submitted by December 1, 1941. Further information can be obtained from the Executive Committee, Institute of Mining Engineers, Santiago, Chile.

VICTOR DOLMAGE has joined the Wright-Hargreaves staff to aid in developing the underground mining program.

B. L. ANDERSON has been appointed to teach crystallography, mineralogy, and petroleum geology in the department of geology of the Johns Hopkins University.

ROBERT THOMAS HILL died in Dallas, Texas on July 28th.

A. O. DUFRESNE has been appointed deputy Minister of Mines for the province of Quebec.

J. W. PEOPLES, associate professor of geology at Wesleyan University, Middletown, Connecticut, is studying the Montana chromite deposits with the U. S. Geological Survey party.

F. W. PARSONS, former associate editor of Engineering and Mining Journal and editor of Coal Age, died in New York City on August 7th at the age of 61.

R. B. ANDERSON is government mining engineer and inspector of mines for the Hartley mining district in Gatooma, Southern Rhodesia.

H. F. BAIN, adviser on mines to the Philippine government, returned from Washington to Manila in September.

RICHARD STOIBER of Dartmouth College is making a study of mineral deposition in the Pitcher section of the Tri-State district.

H. C. BELLINGER, former vice-president of Chile Copper Co., died in Spokane, Washington, July 27th.